

AGENCY FOR INTERNATIONAL DEVELOPMENT WASHINGTON, D. C. 20523 BIBLIOGRAPHIC INPUT SHEET		FOR AID USE ONLY	
1. SUBJECT CLASSIFICATION	A. PRIMARY		
	B. SECONDARY		
2. TITLE AND SUBTITLE The Effect of Liming an Ultisol in Ghana on Maize (Zea mays L.) Yield and Some Soil Properties			
3. AUTHOR(S) Spider Kajera Mughogho, Ph.D. Thesis			
4. DOCUMENT DATE January 1977		5. NUMBER OF PAGES 147	6. ARC NUMBER ARC (For AID use only)
7. REFERENCE ORGANIZATION NAME AND ADDRESS Department of Agronomy Cornell University Ithaca, N.Y. 14853			
8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publisher, Availability)			
9. ABSTRACT Liming is usually aimed at eliminating such effects as low pH, low base status, aluminum and/or manganese toxicity, and P fixation. Field and greenhouse experiments were conducted to study the effect of lime application on maize growth and some soil properties. The work was conducted on an Ultisol in the forest region of Ghana. Field results showed that liming did not have an effect on bicarbonate extractable P (Olsen), 0.1M HCl extractable Zn, and CEC an exchangeable Mg of the top soil. pH and exchangeable Ca increased with increased lime application. On the other hand, the subsoil was not affected by liming the top soil, which may indicate little or no leaching of the Ca. Lime application did not significantly increase maize grain yield in both the major and minor season. The first increment of lime (0.5 t/ha) increased grain yield economically and that subsequent levels did not, with a great yield depression at the highest lime rate (4 t/ha). Short time greenhouse experiments showed that increased lime application significantly increased the bicarbonate extractable P, 0.5M CaCl ₂ pH 1.5 extractable SiO ₂ , pH, exchangeable Ca and also effective CEC in both the top and subsoil treatments. The results showed that the effect of excess lime application was to depress maize growth and that the effect was accentuated when the soil had a low buffering capacity, such as the subsoil in the present study. Response of maize growth to P application was significant, and the effect was greatest at the lowest P rate (45 kg P/ha), although P application did not alleviate the depressing effect of overliming the soils. In fact, highest P and lime rate caused Zn deficiency symptoms. Nutrient uptake was greatly increased with increased P rates, whereas lime depressed most of the nutrients except Ca uptake. Zn application increased maize growth significantly, more especially when lime was applied. One would be led to conclude that since there was a modest response to the first increment of lime in the field experiment, the lime requirement for Kumasi soil is low.			
10. CONTROL NUMBER (For AID use only)		11. PRICE OF DOCUMENT (For AID use only)	
12. DESCRIPTORS		13. PROJECT NUMBER	
		14. CONTRACT NUMBER ATD/ta-c-1104	
		15. TYPE OF DOCUMENT	

THE EFFECT OF LIMING AN ULTISOL IN GHANA ON MAIZE (*Zea mays* L.)
YIELD AND SOME SOIL PROPERTIES

A Thesis

Presented to the Faculty of the Graduate School
of Cornell University
in Partial Fulfillment for the Degree of
Doctor of Philosophy

by

Spider Kajera Mughogho

January, 1977

THE EFFECT OF LIMING AN ULTISOL IN GHANA ON MAIZE (*Zea mays* L.)

YIELD AND SOME SOIL PROPERTIES

Spider Kajera Mughogho, Ph.D.

Cornell University, 1977

Liming is usually aimed at eliminating such effects deleterious to plant growth as low pH, low base status, aluminum and/or manganese toxicity, and P fixation. In the present study, field and greenhouse experiments were conducted to study the effect of lime application (as calcium hydroxide) on maize growth and some soil properties. The work was conducted on an Ultisol in the forest region of Ghana.

Results from both cultivated and uncultivated soil samples indicate that the subsoils were very low in available P, exchangeable Ca, Mg, and K when compared to the surface soils. On the other hand, P adsorption isotherms showed that the subsoils had higher adsorption maxima, an indication that the high clay content and aluminum saturation contributed to the high P fixing capacity of the subsoil.

Field results showed that liming did not have an effect on the bicarbonate-extractable P (Olsen), 0.1M HCl-extractable Zn, CEC, and exchangeable Mg of the top soil. pH and exchangeable Ca increased with increased lime application. The subsoil was not affected by liming the top soil, which may indicate that there was little or no leaching of Ca over the period of the experiment.

Lime application did not significantly increase maize grain yield in either the major or minor growing season. The first increment of lime (0.5 t/ha) increased grain yield economically in both seasons,

but subsequent lime levels did not. A yield depression occurring at the highest lime rate (4 t/ha), when compared to the check plots where no lime was applied.

Short term greenhouse experiments showed that increased lime application significantly increased the bicarbonate-extractable P, 0.5M CaCl_2 at pH 1.5 extractable SiO_2 (Tweneboah et al.), pH, exchangeable Ca, and also effective CEC in both the top and sub soil treatments. Results showed that the effect of excess lime application was to depress maize growth and that the effect was accentuated when the soil had a lower buffering capacity, such as the subsoil in the present study.

Response of maize growth to applied P was significant, and the effect was greatest at the lowest P rate (45 kg P/ha). This may indicate that these soils have a low P requirement, and this was reflected in their low P adsorption maxima. P application did not alleviate the depressing effect of overliming these soils. In fact highest P and lime rates caused zinc deficiency symptoms. Although nutrient uptake was increased with P rates, lime in general depressed nutrient uptake, except for Ca.

Zinc application increased maize growth significantly, more especially when lime was applied. In all treatments, Zn application did not alleviate the depressing effect of high lime rates.

Aluminum in these soils does not seem to be much of a problem, if acid soil infertility is associated with high Al saturation. From the results obtained so far, it can be assumed that liming should be restricted to those situations where Ca is limiting as a nutrient as

opposed to the general theory in most Ultisols and/or Oxisols whereby the main aim is to neutralize exchangeable Al. Soils high in organic matter require more lime than those low in O.M. Therefore, soil pH per se is not a dependable criterion of lime need in this soil.

Since there was a modest response to first increment of lime in the field experiment, one would be led to conclude that the lime required for optimum plant grown for the Kumasi soil was low.

BIOGRAPHICAL SKETCH

The author was born in Gamba Village, Nthalire Area, Chitipa District, Malawi on September 24, 1941. After his early education in Zambia and Malawi, he joined the University of Massachusetts in 1966. In February, 1970 he was awarded a Bachelor of Science degree in Soil Science. In August, 1970 he joined the University of Malawi as an Assistant Lecturer of soil science and also as a Farm Operations Manager.

In August 1972, the author was awarded an AFGRAD Fellowship by the African-American Institute to pursue graduate work at Cornell University where he received a Master of Science degree in Soil Science, 1975. He continued to pursue a course leading towards a doctor of philosophy degree with a major in soil science and minors in International Agriculture (Vegetable Crops Physiology) and Agriculture Economics.

He is a member of the American Society of Agronomy, the Soil Science Society of America and also of the International Society of Soil Science.

DEDICATION

The author dedicates this thesis to the memory of the loved ones:

Elisa Nyakanyimbo

Feggie Nyakajera

Mudumuka Zindonde Kanyimbo

Burton Kajera

Nyabongololo Nyagondwe

the author's mother, sister, grandfather, uncle, and aunt respectively,
who died when the author was still studying.

Their presence would have brought the greatest happiness and satisfaction in the completion of this thesis.

Acknowledgements

The author is very grateful for having been able to continue his studies at Cornell University. He wishes to thank members of his special committee, Drs. Douglas J. Lathwell, Chairman, William C. Kelly, and Thomas T. Poleman for their guidance, advices, and encouragements throughout the course of study. He is also deeply indebted to Dr. Robert M. Weaver who guided the author in the area of soil chemistry.

The author also acknowledges the African-American Institute for providing financial assistance both for maintenance allowance and research. Funds from the U.S. AID were also received for the research work in Ghana.

The author wishes to extend his appreciation to Dr. Henry B. Obeng for permitting the author to use the Soil Research Institute facilities. He is also indebted to Dr. Charles S. Ofori for the guidance and advice while the author was conducting his research in Ghana. The author would also like to express his gratitude to Kwabena A. L. Nyamekye who was of assistance both in the field experiments and in normal social life.

Many people at the Soil Research Institute, Kumasi, Ghana were of great assistance, among whom the services of Mr. Isaac Kanabo, Mr. Potakey, Mr. S. Nave, Mr. P. Adalety, Mr. A. K. Amedume, and Mr. Aidoo, Mr. S. Ansah, Mr. M. Buamah and many others are highly appreciated. Life was made easier for the author because of friends

like Dorothy Hall-Baidu, Kwame Titriku, Kwasi Ampofo, Sultan Malm, and Dr. Amos N. G. Ngongi.

The author appreciates the services from the following people: Thomas Greweling, Charles Burda, and Leland Crawford, Jr. who helped in the plant and soil analytical work. Friends have also been of assistance to the author in one way or another, and these include Dr. and Mrs. Dale E. Bandy who was with the author most of the time during the last part of the work; Dr. and Mrs. Donald C. Kass, who have always been on hand when the author needed any help; and Dennis Shannon, the lunchmate.

Throughout this work, the author has had very close friends whose hospitality, gifts, encouragements, and moral support made the atmosphere for study to be pleasant, and these include Dr. and Mrs. Wilson Sithole, and Mr. and Mrs. Guy Mhone, Mr. Vincent W. Saka, Dr. Ayemou D. Assa, Mr. Phiri J. Chipembere, Frank Sisya, and Dr. Vunde A. Tembo.

The author owes a lot to Diane Shaver who worked day and night typing the final copy of the thesis. Besides this, she has always been a good friend.

Finally, the author would like to thank both the Kajera and Kanyimbo families for their patience, support, and understanding throughout the author's struggles. Especial thanks to his father, S. Kajera Mughogho who has sacrificed a lot to make life easier for the author; and the author is deeply indebted to his brother Jameson Mughogho who spent most of his income for the author's secondary

school education. Brothers like Bosco Kajera, Milton Chisulo, Waluza Kajera, Abraham Kajera, Francis Kajera, and Herbert Masida, and sisters Ayines Nyambale, and Mrs. Matimose Nyirongo have always given encouragements and moral support.

The author owes a lot to his grandmother Nyamtonga Nyachisavya, and uncle Chisavya Kanyimbo for the love, encouragements, and moral support they gave him throughout his youth.

Finally, the author would like to thank his children Suzgo Kajera and Thasya Elisa for their patience during this work. They were dearly missed.

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I.

INTRODUCTION

Soils of the tropics are usually more acid, highly weathered, and leached than the soils in the temperate regions. Although physical conditions may be good, they usually are impoverished in native fertility. They are low in cation exchange capacity, phosphorus, calcium plus magnesium, and pH and may be high in toxic elements like aluminum and manganese. The soils become more acid as more aluminum and iron are released from the clay minerals with the result that Al becomes the dominant exchangeable cation.

The failure of plants to grow on highly acid soils is a problem that has received considerable attention. Liming to reclaim soil properties for adequate plant growth in temperate region soils has been successful when pH is adjusted close to neutrality. To transfer this experience to the old, highly weathered, and leached soils of the tropics such as Ultisols and Oxisols has not been successful. Instead, liming to neutralize levels of Al and Mn seems to be more successful (Coleman et al, 1959; Kamprath, 1970, 1971; Reeve and Sumner, 1970). Liming, therefore, is aimed at eliminating such effects as low pH, low base status, aluminum and/or manganese toxicity, and P fixation.

In cases where toxic levels of soluble Al (and Mn) are often the most limiting factors for plant growth, only sufficient lime to inactivate them is required because any more than that amount may depress yields, and this may be due to decreased P availability or induced trace element deficiencies (Fox et al, 1964; Kamprath, 1967; Reeve and

Sumner, 1970). Kamprath (1970) points out that lime additions to acid soils based on neutralizing the exchangeable Al and/or Mn extracted with unbuffered neutral salt will also provide adequate calcium for plant growth. Furthermore, the kind and amount of lime required for near optimum yields may depend on the soil type. Experimental verification, therefore, indicates that the pH of a soil can only have meaning when not as an independent variable, but instead as a measurement reflecting the interaction of several factors peculiar to a given soil. One has to characterize the parameters interacting with soil acidity in order to get any useful work on liming. Some have reported that Al toxicity may be suspected on almost all soils in Sierra Leone if the pH is below 4.8 or if the ratio of exchangeable Ca + Mg to Ca + Mg + Al drops below 0.1, although the ratio may depend on the species one is dealing with (Bulletin 748, Njala Univ. College, 1974). On the other hand, some work in Puerto Rico has shown that the injury due to low pH may be due to Al on some soils and manganese on the others (Abruna et al, 1974), which clearly indicates that the mode of formation of the soil may indicate the nature of injury. Brans (1971) points out that liming of soils he worked with had no influence on yield within soil pH ranges of 4.3 to 5.5 providing the Ca concentration remains 0.2 meq per 100 gram soil or greater.

If the level of Al in the soil is known, Kamprath (1970) has suggested that 1 1/2 - 2 times meq Ca as lime should be applied to neutralize the toxic effects, although Martini et al.(1974), obtained optimum yields when liming adjusted Al from 0.1 to 0.5 meq/100g which is about 1-5% Al saturation, soil pH from 5.2-5.7.

Although it is reported that liming above the levels required to neutralize Al may cause detrimental effects on the plant, Martini et al. (1974) found no detrimental effects even when the lime rate was 28 tons/ha, where they found that the pH was not raised to pH 7. This was attributed to the high buffer capacity supplied by the exchangeable Al in the soils they worked with. Yuan (1970), for example, points out that even though the reduction of Al toxicity may be the primary function of liming, the increase in cation exchange capacity by liming to a soil pH near neutrality would also be a means to improve the soil chemical conditions. If intensive management of the soils is to be carried out, heavy fertilization with residually acid materials can rapidly increase soil acidity which may induce the formation of trivalent exchangeable Al. Liming soils to near neutrality would, Yuan points out, maintain effective control of the amount of this active Al form. Work by Djokoto and Stephens (1961) and Ofori (1973) in some soils in Ghana has shown that ammonium sulfate aggravates the problem of low pH. They found that pH drops faster in the Savanna soils than forest, and this was attributed to the low buffering capacity of the Savanna soils. Ofori (1973) found no significant response of cassava, maize, and groundnuts to lime, and he concluded that the level of Ca was adequate. Even though the pH of the soil was adversely affected by the use of ammonium sulfate, he suggested that it would not be necessary to advise liming to the peasant farmers. Brams (1971), working with some soils in Sierra Leone also concluded that the supply of Ca was sufficient to preclude response to lime.

In Ghana, it has been a general practice to revert cultivated land into natural fallow, and this has a great influence in recycling of nutrients. The content of natural fallows depends on the nature of vegetation, with the secondary forest giving the highest amounts of nutrients (Nye and Stephens, 1962). Subsoil feeding by fallows transfers mineral nutrients such as phosphorus, calcium, magnesium and potassium onto the surface. The clearing and burning of natural fallow has many disadvantages, one of them being the rapid oxidation of organic matter, and thus a rapid increase in the availability of nutrients to plants. Nye and Greenland (1960) pointed out that the decline in fertility is more rapid under forest than Savanna conditions. Nye and Stephens (1962) observed that in absence of fertilizers, the yields of maize in the fourth cycle were just under half the yields in the first cycle which followed clearing of mature secondary forest.

For the peasants, the rationale for practicing land rotation (shifting cultivation) was that land was plentiful and population relatively sparse. But with the rate of population increase at 2.5-3.0 per cent, and that of urban areas at 9.0 per cent per annum, this will result in increased demand for food. If the idealized formula for food demand is used:

$$d = p + gn \quad \text{where}$$

d = growth of consumption;

p = rate of growth of population;

g = rate of growth of per capita income;

n = elasticity of demand associated with changing income

it is noted that population is one of the factors affecting the increased

demand for food consumption. Thus either fields will have to be expanded to less fertile lands, or if the rest period has to be reduced, better management of the soils will have to be practiced. If the latter alternative is chosen, the intensive use of fertilizers that are acid residual, such as ammonium sulfate may result in lowering of the pH, and thus lowering of the maize yields.

The purpose of the present investigation was to study the effects of liming a Forest Ultisol in the forest region of Ghana. All field and greenhouse experiments were conducted on the Kumasi series, tentatively classified as a typic Paleudult. Parent material of this soil is of residual loam derived from decomposed granite. It is well drained, coarse textured soil with gradually increasing clay content with depth. Chemically it is moderately acid, low in phosphorus, base saturation and organic matter. Due to its coarse texture, its phosphorus fixation capacity is low.

Greenhouse work was aimed at investigating a number of factors that would contribute to the understanding of the problems in the field.

II. DESCRIPTION OF THE AREA AND SOILS OF FIELD AND GREENHOUSE WORK

Climate

Kumasi is approximately 6°45' north latitude in the northern part of the humid forested zone. The climatic description of the Kumasi region is based on 10 years data collected at the Kumasi airport (1966-1975), latitude 6°45'N and 1°36'W, and height of barometer above mean sea level is 292.8 meters. Average monthly temperature varies less than 3°C around a yearly average of 25.8°C (see Fig. 1). However, the differences between daily maxima are substantial.

The mean annual precipitation is 1498 mm and is bimodially distributed, with the main rainy season starting in March or April and reaches a maximum precipitation in May-June. A short dry season is in August and a lower maximum rainfall for the minor season is recorded in September-October.

Soils

The soils of the Kumasi series are red gritty clay loams and clays developed over deeply weathered granite. Work on some samples from the area indicated that the clay size fractions (<0.002mm) are composed from about 65-75% kaolinite, 20-23% amorphous material, and 6-8% iron (R. M. Weaver & P. P. Adams, 1974. Unpublished Research Report, Cornell Univ., Ithaca, N. Y.). The sand fractions are predominantly quartz.

These soils are of the upper slope position in the same catena with the well to moderately well drained Akroso series, the imperfectly drained Nta series and the poorly to very poorly drained Ofin series. Kumasi soils have moderately rapid internal drainage and have a fairly good moisture holding capacity.

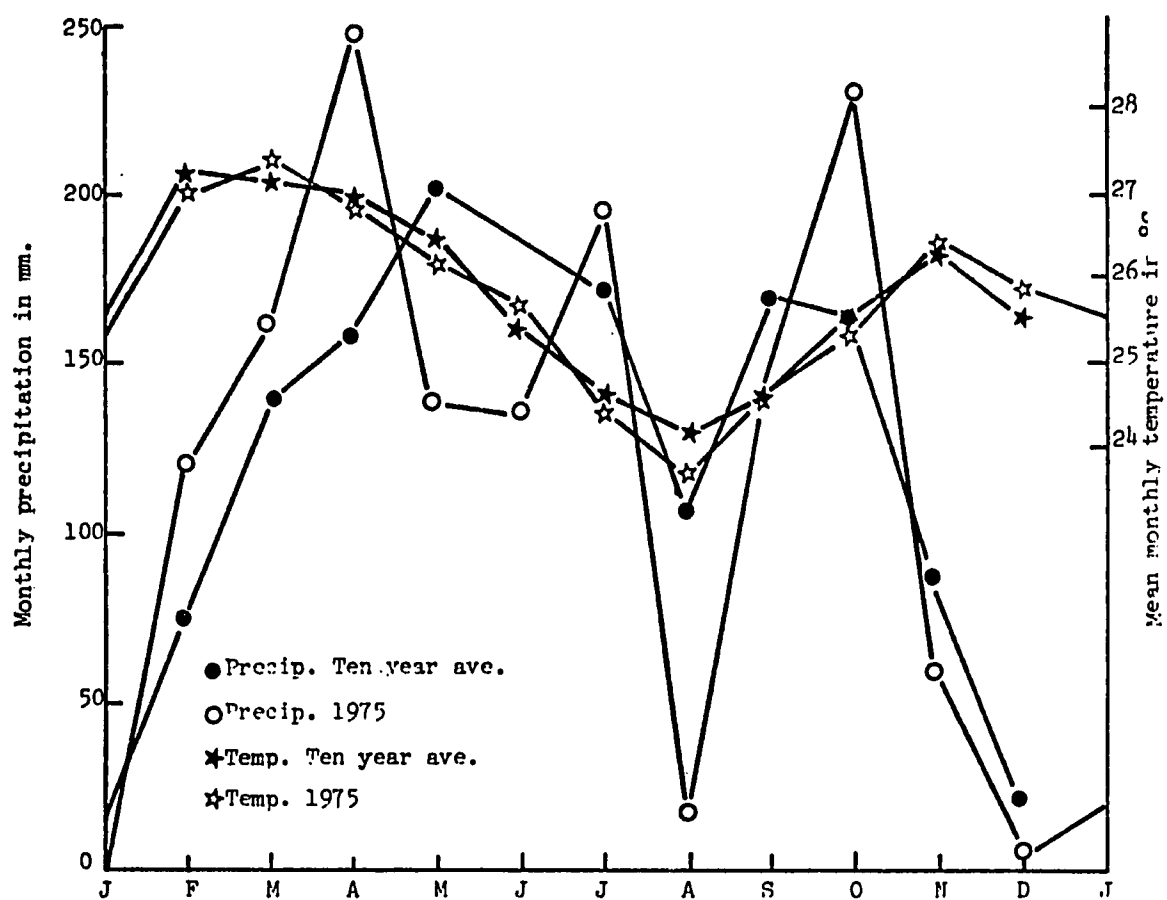


Figure 1. Average monthly temperature and precipitation at Kumasi Airport for the year 1975 and average from 1966-1975.

These soils are highly weathered, moderately acid, with the organic matter around 8% in the surface horizon (0-7 cm), and drops very rapidly in the sub-surface horizons. The natural fertility is very low mainly due to low pH, low cation exchange capacity, low exchangeable Ca and Mg, and low phosphorus.

Presently these soils are classified as Forest Ochrosols according to the Ghana classification system, and Typic Paleudult USDA system. These soils have to be reclassified in the USDA system once more information is gathered since the lower subsoil has pieces of weathered rock, which increases in abundance with depth into the weathered substratum.

Although the soils have good physical conditions for plant growth and that moisture retention in the subsoil is fairly good, the upper horizons tend to dry out rapidly during prolonged dry spells. These soils are suitable for tree crops which include cocoa, coffee, oil palm, and citrus. Food crops such as plantains, cocoyam, bananas, maize, and cassava do well on these soils, but management practices should aim at conserving soils moisture in the dry season.

The site where the field experiments were conducted was cleared and burned in June, 1973 and the regrowth cut but not burned in December, 1973. This area had been in bush for at least 14 years and had not been cropped for at least 22 years (Dr. C. S. Ofori--personal communication).

Materials and Methods

Characterization of Soil Samples

Physical and chemical properties

Organic matter was determined by the modified wet combustion method of Walkley and Black, as described by Greweling and Peech (1965). The pH was measured in water and 0.01M CaCl_2 at a soil:solution ratio of 1:2. The glass electrode of the pH meter was positioned in the supernatant.

Cation exchange was measured by saturation with neutral N ammonium acetate. The soil was then washed with isopropyl alcohol; leached with 10 per cent weight/volume NaCl in 0.005N HCl; and NH_4 in the extract was determined by nesslerization. Ammonium extraction was used for exchangeable bases. The organic matter in the extracts was destroyed by H_2O_2 and silica dehydrated with concentrated HCl. Lanthanum sufficient to give a 5% concentration was added to the residue, and the exchangeable bases were determined by the atomic absorption spectrophotometer. Exchangeable acidity was measured by the BaCl_2 -TEA method (Greweling and Peech, 1965).

A comparison was made by determining the exchangeable cations in 1N KCl extracts, namely Al, Ca, and Mg. The per cent aluminum was calculated according to the following equation:

$$\% \text{ Aluminum} = \frac{\text{Al}}{\text{Al} + \text{Mg} + \text{Ca}} \times 100$$

10 grams of soil were extracted with 50 ml of 1N KCl. After shaking the soil plus KCl solution for 30 minutes, the soil suspensions were centrifuged for 20 minutes. The soils were then washed with 50 ml of KCl (two washings); the extracts were mixed, and cations determined as suggested by Kamprath (1967). Ca and Mg were determined by the atomic absorption spectrophotometer, and Al in solution was determined by the aluminon

method (Black, 1965).

Phosphorus Chemistry

Phosphorus adsorption.

Phosphorus adsorption isotherms were determined as described by Fox et al. (1971). Four gram air-dried samples were equilibrated at room temperature with various amounts of phosphorus (KH_2PO_4) in 0.01 M CaCl_2 at 1:10 soil:solution ratio for 48 hours of continuous shaking; P in solution was determined by the ascorbic method of Watanabe and Olsen (1965). P adsorption data were analyzed by the Langmuir equation as described by Olsen and Watanabe (1957):

$$\frac{C}{X} = \frac{C}{b} + \frac{1}{kb} \quad \text{where}$$

x = μg of P adsorbed per gram of soil;

b = adsorption maxima

c = equilibrium solution concentration of P;

k = constant and related to energy of adsorption.

Organic-P estimation.

Saunders and Williams (1955) method was used to estimate organic P which involved the ignition of soil samples at 550°C for one hour followed by extraction of the samples with 2.0N H_2SO_4 for 17 hours. P in solution was determined as above.

Samples taken from Kumasi for analysis at Cornell: 1/

1. An area cropped for 20 years and unfertilized for at least seven years - Kumasi series.

Sample 1. 0-20 cm (Ap)-a composite from three spots within a radius of 3m.

Sample 2. 30-40 cm (B)-a composite from the same three spots as sample 1.

pH 4.6 by indicator.

2. An area cleared and burned in June, 1973 and regrowth cut but not burned in December, 1973. This has been in bush at least 14 years and had not been cropped at least 22 years. Kumasi series.
- Sample 3. 0-20 cm (A1)-composite from three spots within a radius of three meters.
- Sample 4. 30-40 cm (B)-a composite from three spots of sample 3. pH 5.0-5.2 by indicator.
- Sample 5. 0-20 cm (A1)-a composite from three spots in the newly cleared area, about 15 meters from sample 3.
- Sample 6. 0-20 cm (Ap)-a composite from five places within a radius of 5 meters in an area fertilized last eight years ago and now prepared to plant ginger.
- Sample 7. 0-20 cm (Ap)-a composite from five places in an area cropped to unfertilized maize in 1973 and with broadcast application of phosphate within past month. Fertilized at least some years prior to 1973.
- 1/ D. J. Lathwell and M. G. Cline. 1974. A Report on the Potential for Collaboration of Cornell University with an Institution in Ghana for Extension of Research under Contract AID/csd 2490 to Africa and Appraised during Consultation in Ghana from April 23 to May 8, 1974.

Results and Discussion

Some chemical analyses of soils sampled from Kumasi for characterization.

It is reported that in cropped areas on the Kumasi soil, roots of maize proliferate in the plowed layer but few penetrate the subsoil (Lathwell and Cline, 1974). Those that penetrate the subsoil had few or no feeder roots, and this was interpreted as chemical toxicity rather than mechanical impedance. In view of this fact, soil samples were taken from various fields so that some preliminary work could be done in the laboratory at Cornell University to determine whether the failure of roots to penetrate and proliferate into the subsoil was chemical.

Results in table 1 show that in general, the cation exchange capacity of these soils is low, and although there is a fairly good supply of nutrients in the top soil, the subsoil is very low in cations such as Ca, Mg, and K. And the pH in the subsoil is much lower than that of the surface, thus a lower percent base saturation.

Aluminum in these soils does not seem to be much of a problem, if acid infertility is associated with an increased Al which usually increase in mineral soils once the pH is low. In all cases in the present study, the Al saturation is below the level that likely is toxic to plants.

Just like Al, manganese toxicity is one of the hazards to plants growing in acid soils (Vicente-Chandler et al. 1969; Abruna et al. 1974). In view of this fact, a study was made to determine the levels of Mn. The study failed to reveal any substantial amounts to be of any harm to plants (Table 1). This is shown on the study of the exchangeable Mn as estimated by neutral $\frac{N}{NH_4}OAc$ pH 7. Thus a study of the "Easily Reducible" manganese

Table 1. Some chemical analyses of soil samples from Kumasi.

Sample	C.E.C.	Exc. Acid	Ca	Mg	K	Na	Mn	Σ Cations	B.S.
meq/100g									%
1	8.2	5	2.99	0.53	0.18	0.015	0.022	8.737	42.5
2	10.0	7	1.56	0.33	0.04	0.024	0.008	8.962	21.8
3	9.5	5	4.31	1.03	0.27	0.008	0.002	10.620	52.9
4	9.8	5	2.08	0.79	0.12	0.012	0.003	8.005	37.4
5	8.7	5	3.23	0.64	0.27	0.008	0.003	9.151	45.3
6	9.0	6	3.67	0.66	0.18	0.012	0.012	10.534	42.9
7	7.8	6	2.83	0.57	0.20	0.010	0.640	10.250	35.2

Some chemical analyses of soil samples from Kumasi (continued).

Sample	pH	O.M.	Al	P
	$\frac{H_2O}{2}$	KCl	%	ppm
1	5.5	5.0	2.1	28
2	5.0	4.5	1.1	57
3	5.8	5.4	2.7	25
4	5.4	4.8	0.8	15
5	5.5	5.0	2.7	13
6	5.3	4.8	2.3	17
7	5.3	4.8	2.3	1

was made in order to investigate the potential of the non-exchangeable (easily reducible) Mn. Ammonium acetate (pH 7) plus 0.2 per cent hydroquinone (Hoyt & Nyborg, 1971) and acidified hydroxylamine hydrochloride procedures (pH 2) (Chao, 1970) were used. In both cases, the easily reducible Mn was far much higher than the exchangeable Mn, but that this fraction decreased tremendously in the subsoil, which may indicate that it cannot be a contributory factor to the failure of the root growth in the subsurface (Table 2). It would seem plausible to conclude that the surface soil, instead, would impede root development.

A comparison of the two methods for estimating easily reducible Mn does not seem to show any difference in the two procedures, except that the acidified hydroxylamine was not as efficient in selectively dissolving Mn as the NH_4OAc + hydroquinone since the former also extracted a substantial amounts of iron. Ca and Mg remained fairly constant in both procedures.

In conclusion, then, the Mn saturation in these soils seems to be too low to be of any toxic levels. Abruna et al. (1974), for example, found that whereas Humatas Clay showed low levels of Mn, Coto Clay was very high in Mn, with 200 ppm determined as exchangeable Mn and 2000 ppm as easily reducible Mn. Work in Puerto Rico has led some workers (Vicente-Chandler et al. 1969; Abruna et al. 1974) to conclude that Ultisols seldom present a Mn problem whereas Oxisols frequently do. Similarly, work in Hawaii has shown that Low Humic Latosols are high in Mn oxides, and that when they become more acid they may have high levels of soluble Mn whereas Hydrol Humic Latosols have a low level of Mn as to cause deficiency in sugarcane (Ayres, 1961-quoted by Pearson, 1975). Reeve and Sumner (1970) found similar re-

Table 2. Comparing two extractants for dissolution of "Easily Reducible Manganese".

Sample	1N NH_4OAc + Hydroquinone		0.1N $\text{NH}_2\text{OH.HCl}$ + 0.01N HNO_3	
	<u>Mn</u>	<u>Fe</u>	<u>Mn</u>	<u>Fe</u>
1	218	1.77	232	60
2	48	1.32	45	20
3	270	1.58	340	60
4	74	0.75	92	30
5	225	2.34	290	60
6	360	1.81	395	80
7	195	1.77	218	55

sults where liming reduced extractable Mn to near zero in a Natal Oxisol.

Some Chemical Analyses of Soil Samples Taken From the Check Plots of the
Field Lime Experiment

Estimation of aluminum saturation in 1N KCl extracts.

Aluminum saturation was determined using the following formula:

$$\% \text{ Al saturation} = \frac{\text{Al}}{\text{Ca} + \text{Mg} + \text{Al}} \times 100$$

with the amounts of cations expressed as me per 100 grams. Data in Table 3 clearly indicates that the subsoil in general has a greater percentage of Al saturation than the surface soil, although in only two cases would this saturation be anywhere near detrimental to the growth of maize (Brams, 1971; Kamprath, 1972). The greater amounts of exchangeable Al in the subsurface horizons as compared to the surface horizon can be explained by looking at the nature of the two soils. Whereas the top soil has more than double the organic matter as the subsoil, the clay content of the later is almost twice that of the surface soil (Weaver and Adams, Research Report, 1974).

Following the schematic diagram as presented by Pionke and Corey (1967):

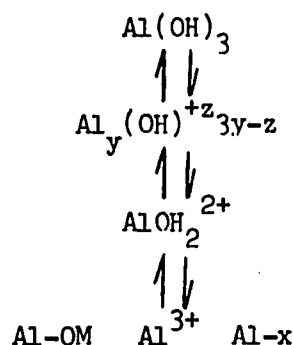


Table 3. Estimation of aluminum saturation in 1N KCl extracts.
(planting time).

	Ca	Mg	Al	Σ Cation	%Al	pH
<hr/>						
meq/100g						
<hr/>						
<u>Top Soil</u>						
1.	3.96	0.68	0.00	4.64	0.05	5.28
2.	1.70	0.56	0.29	2.55	11.36	4.30
3.	3.29	0.95	0.02	4.26	0.49	4.50
4.	3.69	1.15	0.01	4.85	1.20	5.08
5.	2.10	0.56	0.18	2.84	6.30	4.47
6.	4.49	1.37	0.01	5.87	1.50	5.95
<hr/>						
<u>Subsoil</u>						
1.	1.70	0.39	0.14	2.23	6.44	4.45
2.	0.65	0.30	1.02	1.97	51.98	3.95
3.	1.30	0.56	0.33	2.19	15.14	4.20
4.	0.90	0.44	0.47	1.81	25.82	4.21
5.	0.65	0.30	0.80	1.75	45.84	4.08
6.	1.30	0.68	0.02	2.00	1.00	4.55

the KCl extract would only remove Al^{3+} , which represents the activity of hydrated trivalent Al ions in solution and exchangeable Al (Al-x). It is reported that both the Al-OM, (Al complexed by organic matter) and $Al_y(OH)^{+z}_{3y-z}$, (Al polymerized and probably residing on particle surfaces), which are non-exchangeable are included in the acid form (Pionke and Corey, 1967; Clark and Nichol, 1966; Evans and Kamprath, 1970). It can be concluded, then, that the increase in organic matter in the surface soil in the present study increases the Al-OM. Organic matter decomposition would, therefore, increase the exchangeable form. Liming, then, would be aimed at neutralizing both the exchangeable form and the non-exchangeable forms, although neutralization rate of the non-exchangeable portion appears to be relatively slow (Bhumbla & McLean, 1965).

Work by Evans and Kamprath (1970) shows that soils low in organic matter required less lime to neutralize the Al, even though they had a high percentage of Al saturation, whereas soils high in O.M. required more lime. It is possible that Al formed insoluble Al organic complexes. Thus, as Clark and Nichol (1966) suggested, it is necessary to take into account both the pH and solubility of Al in estimating the liming needs of organic soils. In the other work by Clark (1966), he concluded that soil pH whether determined in water or neutral salt does not give a quantitative estimate of active acidity nor the total acidity and would be a poor basis for accurate lime estimation.

Lastly, it is important to note that the high pH's in soils 1, 4, and 6 of the top soil was due to the fact that on these spots there were a lot of charcoal residues, and this was because the bush might have been burned on the spots. This, it is concluded, resulted in an increased base saturation. This is in agreement with the work carried out in Peru by the Soil

Science Department, North Carolina State Univ. (1973 and 1974) in that burning markedly increased the base status of the Ultisols. Exchangeable Ca, Mg, and K contents approximately tripled whereas the per cent aluminum saturation decreased. On the other hand, bulldozing did not have any effect on the bases. Thus, other things put aside, burning vegetation on the spot might be considered another way of liming the soil. Nye & Greenland (1964) also found similar results whereby the pH rose from 5.2 to 8.1 after burning (0-5 cm).

Adsorption of phosphorus.

The phosphorus adsorption isotherms were used to characterize the soils with regard to phosphorus requirements. The correlation coefficients that resulted when the adsorption data (Table 4) were fitted to the Langmuir equation:

$$\frac{C}{x} = \frac{1}{kb} + \frac{C}{b}$$

were extremely high, ranging from 0.992-0.999. The higher correlation shows that within the range of concentrations used in the present study, the Langmuir equation best describes the P adsorption.

From the present results it is quite clear that the top and subsoil are very different in the adsorption capacity, with the subsoil showing a high adsorption maxima (b) and also a high bonding energy (k). In all cases, the values are lower than those reported for some highly weathered soils of Hawaii (Fox et al. 1970), Puerto Rico (Weaver et al. 1975), Brazil (Weaver, 1975), and Malawi (Mughogho, 1975). One would, therefore, conclude that the P requirements for these soils is far much less, and that adding more P than is needed may not only be wasteful and uneconomical, but may also induce some nutrient imbalances.

Table 4. Adsorption isotherm data showing the r-values, adsorption maxima, slopes, and intercepts for the soil samples from the check plots from the field lime experiment. 1/

	r-value	Slope	Intercept	Adsor-Max.
<u>Top Soil</u>				
1.	0.998	0.004307	0.002571	232
2.	0.993	0.004037	0.001495	248
3.	0.997	0.003841	0.001625	260
4.	0.993	0.003483	0.001667	287
<u>Sub Soil</u>				
7.	0.999	0.003228	0.001051	310
8.	0.995	0.003094	0.000646	323
9.	0.996	0.002895	0.000598	345
10.	0.992	0.002850	0.000625	351

1/ Adsorption isotherms were done on 1 mm sieved soil samples.

Estimation of organic phosphorus.

Two weeks after planting maize in the Cornell University Phosphorus Fertility Experiments, it was observed that in the check plots many plants started purpling and as time passed, these were stunted. Although these symptoms disappeared gradually, maturity in the check plots was delayed. The disappearance of the P deficiency symptoms may be either due to the mineralization of organic phosphorus, and thus rendered available for plant use or as a result of the development of the root system necessitating the plant to utilize nutrients or a combination of the two theories. In view of this fact, an estimate of organic P was made to see if it can be potentially available for plant use.

Table 5 shows some of the values for organic P estimated on samples from the lime check plots. It is observed that the amount of organic P estimated by the ignition method shows a greater percentage of the total P to be in the organic form. In general the top soil exhibits a higher amount of organic P than the subsoil, although that is also true of the total P. On percentage basis, the subsoil indicates that a greater portion of the total P is in the organic form, although organic matter is low. On the other hand, Cunningham (1960) found that in some soils in the cacao experiments in Ghana the organic P was in the order of 75 and 55 per cent of the total in 0-5 cm and 5-15 cm horizons respectively.

It should be mentioned here that the ignition method is known to give erroneously high estimates if there is an increased extractability of the inorganic P induced by ignition. Black and Goring (1953) reported that ignition may increase the dilute-acid solubility of certain naturally occurring iron and aluminum phosphates. Other work by Williams et al. (1970) confirmed this in that nodules from strongly weathered soils-

Table 5. Organic-P estimates by the ignition method on some samples from the check plots (ug/g).

%O.M.	Total-P	Inorg-P	Org-P	%Org-P
<u>Top Soil</u>				
1. 2.6	130	74	56	43
2. 3.3	109	26	85	78
3. 3.3	149	27	122	82
4. 1.7	139	44	95	68
5. 3.3	124	33	91	73
6. 3.3	151	51	100	66
<u>Subsoil</u>				
7. 0.9	85	23	62	73
8. 0.9	85	14	71	84
9. 1.2	99	10	89	90
10. 0.9	95	22	74	78
11. 0.9	92	16	76	83
12. 0.9	76	16	60	79

dominantly composed of gibbsite and kaolinite-extractable inorganic P increased sharply between 550°C and 650°C. Norrish (1968) reported that Plumbogummite group of phosphate minerals when heated above 400°C, lose their structural water and become amorphous in which form they can be extracted by $2N H_2SO_4$.

Work by Acquaye (1963) on cacao has shown a close correlation between the organic phosphorus contents of the soils and the yield of cacao, which may support the fact that organic P may be available for plant yield. It can then be concluded that some of this P which is rendered available upon heating may be of importance for plant use.

III. THE EFFECTS OF LIME APPLICATION ON SOME SOIL PROPERTIES AND MAIZE

YIELD

Introduction

Crop response to lime application depends not only on the soil factors such as low pH, Ca, and P availability, and high contents of Al and/or Mn, but also on the types of species grown, in addition it has been found that the difference may occur among varieties of the same species (Foy et al., 1967; Spain et al., 1974).

The method and mode of application of lime depends on how the acid infertility has been identified. In most temperate regions, for example, lime is applied to raise the pH to some level whereas in most of the soils in the tropics the application of lime is used to neutralize Al which may be toxic to crops if available in large quantities (Coleman et al., 1959; Kamprath, 1972; Reeve & Sumner, 1970; Brams, 1971).

The response varies from negative on soils where a slight increase in lime causes detrimental effects, thus depressing yield, to a positive effect whereby even large amounts of lime still provide a positive response. In most cases, overliming injuries in the tropics occur in many cases due to nutrient imbalances. Brams (1971) reported small depressions of both maize and groundnut yields on the Oxisols he worked with in Sierra Leone, and he overruled micronutrient deficiency as the cause of the depression. Fox and Plucknett (1964), for example attributed the overliming depression effect to induced Zn deficiency and also depressed P uptake.

Work on oil palms in Nigeria reported by Hartley (1968) showed oil palm yield depression only when superphosphate was applied, indicating that the injury was due to depression by P and lime. Thus, overliming may be due to intensification of certain micronutrient deficiencies such as Zn, B, and Mn.

Maize has shown a tremendous response to lime application in cases where lime has been applied to eliminate the detrimental effect due to Al toxicity (Abruna et al., 1974). Pearson (1975) reports some work done by Soares and associates in Brazil where they found good response to lime when the Al saturation was reduced to less than 10 per cent, but as pointed out earlier, this may depend on the type of soil. Nye and Greenland (1960) concluded that on maize the response to lime occurs only when the pH falls below 5.0. Brams (1971), for example, in Sierra Leone, found only small increases in yield when lime was applied at lower rates, even when the aluminum saturation was 80 per cent. Foster (1970) reported no yield response to lime when the initial pH was above 5.5. As pointed out earlier, it is important to note that soils high in organic matter may require more lime.

In Ghana, work has been reported on the effect of lime, and most of the work has been on continuously cropped experiments (Djokoto & Stephens, 1961; Ofori, 1973). Djokoto and Stephens (1961) reported increased maize yields due to lime on the phyllite sites at Kwadaso-Kumasi. The pH fell much faster in the Savanna soils than on the well buffered forest soils, they added. Later Ofori (1973) reported increased maize yields when lime

was applied as quick lime at the rate of 1143 kg/ha/annum once every four years, and this was attributed to the direct effect of lime on the pH of the soil, since ammonium sulfate significantly reduced the pH.

It is not known to what degree overliming these Kumasi soils will influence some of the soil properties, and thus plant growth. Thus the aim of the present study is to study the influence of liming on some soil characteristics and maize yield.

Materials and Methods

Field Experiment

1. Major season

A randomized complete block design was established with six replicates and five lime treatments in plots of 6 by 10 meters. The experiment was laid out on the area which had been under forest for more than 20 years. Soil samples were taken from the check plots at time of planting for laboratory analyses at 0-15 cm and 15-30 cm depths. Each depth of sampling was composited, dried and passed through a 2 mm sieve and stored.

On April 4, 1975 lime was applied to the plots at 0, 1/2, 1, 2, and 4 tons per hectare as Ca(OH)_2 and worked into the soil with a hoe to a depth of 10 cm. On April 10 and 11, 1975 the experiment was seeded to Composite 4 maize variety (Zea mays L.) at 90 by 30 cm, three seeds per hole. Basal application of 30 kg N, 45 kg P, and 30 kg K applied as ammonium sulfate, triple superphosphate and muriate of potash respectively

done at time of planting. The fertilizers were placed 4 cm beside and 4 cm below the seed.

On May 5, 1975 the maize was thinned to one plant per hill to give approximate number of 36,000 to 37,000 plants per hectare. On this same day, 20 plants from each plot were collected for tissue analyses. The samples were dried at 70°C for three days, ground and stored in plastic bags. After the first weeding on May 13, the maize was side-dressed with additional 90 kg/ha N as ammonium sulfate.

Maize was harvested on August 18, 1975 from the middle 9 rows of 5 meters, to give a total area of 40 m² (5 x 8m). Soil samples were also collected from each plot at 0-15 and 15-30 cm and stored for laboratory analyses.

a. Crop response:

- i. Plant tissue test - Plant samples were analyzed for K, Ca, Mg, and Zn (procedures outlined by Greweling, Agron Mimeo 6622, 1966).
- ii. Yield-Grain yield was determined from the center 40 m² and expressed in tons per hectare at 14% moisture equivalent.

b. Soil analyses:

Chemical analyses was done on the soil samples. The procedure for determining exchange capacity, exchangeable bases, pH, organic matter, and Al saturation are already outlined in the second chapter. Zinc was extracted with 0.1N HCl procedure at 1:10 soil solution ratio (Trierweiler & Lindsay, 1969), and Zn in solution was determined by atomic absorption spectrophotometry.

2. Minor Season:

After removing the stalks from the plots and weeding, the plots were relaid to give a spacing of 75 cm between rows and 30 cm within rows. Variety K4 sorghum was planted on September 15, 1975 at 10 seeds per hole because the sorghum seed had a very poor germination percentage (25%). Since the rainfall was erratic, only P and K were applied at 45 kg and 30 kg per hectare respectively as triple superphosphate and muriate of potash.

The emergence was very poor since there was not much moisture in the soil and the viability of the seed was low. In view of this fact the sorghum was uprooted and a short season maize variety, Mexican 17, was planted on October 14, 1975 at 40 cm spacing. Three seeds were planted per hole, which were thinned after four weeks to give an approximate population of between 36,600 and 37,000 plants per hectare.

Crop Response:

Total dry matter (grain + cobs + stover), grain, cobs, and stover were determined from the center 40² and expressed in tons/ha.

Results and Discussions

Soil Chemical Properties

Data for the soil samples from the check plots are summarized in Table 6. There was a great variability in the pH's of the samples which ranged from 4.5 to a high of 5.8 in the top soils and 4.0 to 4.6 in the subsoils. One of the main reasons for the variability was that some of the wood in the field was burned on the spots, thus raising the

Table 6. Estimation of aluminum saturation in 1N KCl extracts
(time of harvest).

	Ca	Mg	Al	Cation	%Al	pH
	meq/100g					
	<u>Top Soil</u>					
1.	4.09	0.74	0.01	4.84	0.12	5.3
2.	3.69	1.15	0.05	4.89	1.04	4.5
3.	4.99	1.59	0.01	6.59	0.09	5.0
4.	2.89	0.68	0.01	3.58	0.64	4.7
5.	4.49	1.15	0.02	5.66	0.41	4.8
6.	5.99	1.44	0.01	7.44	0.13	5.8
	<u>Subsoil</u>					
1.	1.70	0.35	0.01	2.06	0.63	4.6
2.	0.90	0.30	0.56	1.76	31.77	4.1
3.	1.70	0.62	0.36	2.68	20.34	4.3
4.	0.90	0.20	0.94	2.04	46.33	4.0
5.	0.90	0.25	0.88	2.03	40.40	4.1
6.	2.50	0.56	0.02	3.08	0.71	4.4

pH, whereas in the spots where the subsoil was brought to the surface, the pH tended to be low since the subsoil pH in the present study is lower than that of the top soil. Work in Peru (North Carolina State Univ., Soil Sci, Report on Latin Amer. Study of 1973 and 1974) has also shown that burning the vegetation on the fields raised the pH and a consequent reduction in Al saturation. In Ghana, Work by Ahn (1970), Nye and Greenland (1964), and Cunningham (1960) found similar results in that burning bush in the fields increased the pH.

Just like pH, Ca and Mg varied markedly in the check plots. This was the same case with Al saturation. The Al content of the top soil was extremely low when compared to that of the subsoil, but in both cases, there did not seem to be sufficient Al to cause any harm to the plant growth. The effective cation exchange capacity was in the order of 5.5 me/100g for the top soil and 2.27 me/100g for the subsoil. This is in agreement with the findings of Kamprath (1970) who reported that the effective pH of highly weathered Ultisols and Oxisols is low.

From the data summarized henceforth, then, one can deduce that liming such a set of soils would require many studies in microvariabilities since liming would bring a lot of side effects to the plots that already have a high pH. Not only that, but also that the subsoil brings its own variations in properties.

The data from the lime experimental plots is summarized in Table 7 and Appendix Tables 1-14. Lime significantly increased the Ca content of the soil ($P = 0.05$), whereas the exchange acidity decreased with increased lime application ($P = 0.05$). On the other hand, lime application

Table 7. The effect of lime application on some soil chemical properties (Field).

Treat	O.M.	P	Zn	pH		CEC	E.A.	Ca	Mg	K	Σ Cations	B.S.
t/ha	%	— ppm —		H ₂ O	CaCl ₂	me/100 g						%
TOP SOIL												
0	3.6	5.8	1.9	5.6	5.4	12.9	7.2	4.74	1.12	0.17	13.2	46
1/2	3.8	6.0	2.0	5.9	5.6	13.4	6.7	5.75	1.22	0.12	13.8	52
1	3.7	6.9	2.1	6.1	5.8	13.2	6.2	6.16	1.16	0.16	13.6	56
2	3.6	6.0	1.7	6.1	5.8	13.0	6.3	6.20	0.96	0.13	13.6	54
4	3.7	6.5	1.8	6.6	6.4	12.0	4.0	9.50	1.32	0.13	15.0	71
SUBSOIL												
0	1.3	1.2	0.62	5.0	4.6	7.8	6.2	1.58	0.49	0.08	8.3	26
1/2	1.4	1.6	0.55	5.2	4.8	8.0	4.8	1.98	0.60	0.09	8.2	39
1	1.3	1.3	0.53	5.3	5.0	7.4	5.0	1.64	0.56	0.10	7.2	32
2	1.2	1.5	0.45	4.9	4.6	7.2	5.7	1.54	0.42	0.08	7.7	28
4	1.4	1.3	0.70	5.2	4.8	7.3	5.2	1.93	0.52	0.08	7.7	33

has no effect on the subsoil exchangeable Ca or exchange acidity, which clearly indicates that there was no substantial movement of Ca into the subsoil. Djokoto and Stephens (1961 b) found similar results 8 years after lime application. Similarly, liming had no effect on the other ions, namely Mg, K, P, and Zn in both the surface soil and subsoil. Organic matter was not affected by lime application.

The cation exchange capacity as determined by the direct method was not affected by lime application. On the other hand, C.E.C. as determined by the sum of cations ($\sum \text{Cations}$) increased only at the highest lime rate (4 t/ha), and this is attributed to the increase in water soluble Ca (Black, 1965). This is true in neutral or near neutral soils where soluble Ca increases. Kamprath (1970), working with some highly weathered Ultisols found that additions of lime raised not only the pH but also the effective C.E.C. This may have been due to the increase in the exchangeable Ca which was taken as the measure of the total acidity neutralized. de Villiers and Jackson (1967), working with Ultisols, pointed out that the pH-dependent cation exchange negative charge (CEC) of soil clays may result from the presence of pedogenically formed aluminous chloride which is a complex consisting of a positively charged hydrous alumina attached to negatively charged silicate. The initially blocked isomorphous substitutional negative charge of the layer structure was released by deprotonation of $-\text{AlOH}_2$ groups of the positively charged hydroxy alumina upon addition of base (Jackson, 1963; de Villiers & Jackson, 1967 a & b).

On the other hand, the subsoil C.E.C. and sum of cations ($\sum \text{Cations}$) were not affected by lime application which, again, goes to prove that there was not much movement of Ca into the subsoil. In general, the subsoil was less fertile than the surface soil, which is typical of the forest soils where nutrients are recycled from the sub-surface horizons to the surface. Differentially, the subsoil was more acid and had more Al than the surface soil. One of the reasons why there was less Al in the surface soil may be the fact that most of the Al was complexed by the organic matter (Al-OM), a form which cannot be removed by the neutral salt such as 1N KCl.

Crop Response:

On April 25, 1975 (two weeks after planting) there were a few plants that showed some signs of purpling, an indication that P was deficient, and that this was mostly in spots where the subsoil was brought to the surface either through the digging to uproot the trees or by deep and uneven plowing. Gradually, these symptoms disappeared which indicated that either the plants had established a well developed root system or that during the later part in the growing season there was some mineralization of organic phosphorus which might have benefited the plant.

Zinc deficiency symptoms (bleaching of young leaves in and around the whorl on either side of the midrib) were observed in most plots, irrespective of the lime treatment, although they were accentuated by high lime rates. Just as for P, the Zn symptoms disappeared with time. Osiname et al. (1973) observed similar results where zinc was not applied in that

the deficiency symptoms gradually disappeared, and they suggested that either the plant was benefiting from zinc mineralized from the organic forms or that the plants had developed a root system that would survey a greater area for nutrients.

The prevalence of Zn deficiencies in these soils may not only be as a result of the top soil being exposed to the surface, but also the fact that high pH's resulting from liming or burning of brush on the spots can cause nutrient imbalance. Work in Peru has shown that burning of brush on the spot raises the pH, and thus neutralizes the Al (North Carolina State Univ., Soil Sci. 1973, 1974). Cunningham (1960) also observed that in cocoa fields in Ghana on newly cleared land where brush was burned in place, Zn deficiency symptoms occurred, and this induced deficiency was attributed to the raised pH of the soil. In the present case, then, it would seem plausible that Zn deficiency occurred mostly where the soil Zn was low and that liming such a soil accentuated the deficiency.

Grain yield results are summarized in Table 8. There was a slight response to lime application, although this was not significant at any reasonable level of significance. There was an increase in yield at the lowest lime treatment, with 0.47 ton/ha increase over the check treatment, and this was slightly economical. Subsequent lime treatments were very uneconomical, and that at the highest lime rate (4 tons/ha) there was even a yield depression (-0.089 ton/ha) over the check treatment.

In acid soils of the tropics, Ultisols and Oxisols, liming is usually intended for those soils where exchangeable Al is the predominant cation,

Table 8. The effect of lime application on grain yield.

Treat/Rep.	I	II	III	IV	V	VI	MEAN
Lime tons/ha	tons/ha						
0	5.15	4.99	4.67	5.28	4.44	5.43	4.99
1/2	5.32	4.91	5.43	6.30	6.15	4.75	5.47
1	5.62	4.63	5.37	5.32	5.60	4.76	5.22
2	5.13	5.20	5.16	5.22	5.30	5.71	5.45
4	5.36	4.67	4.81	4.96	4.80	4.78	4.90
Mean	5.32	4.88	5.09	5.42	5.46	5.09	5.21

ANOVA

Source	df	SS	MS	F
Treatment	4	1.6210	0.4053	2.14
Replicates	5	1.2489	0.2498	1.32
Error	20	3.7837	0.1892	
Total	39	6.6526		

Table 9. Maize yield and foliar composition at different levels of lime application.

Treat	Yield	Ca	Mg	K	P	N	Zn
ton/ha		%					ppm
0	4.99	0.63	0.33	7.09	0.37	3.41	25.5
1/2	5.46	0.68	0.33	7.52	0.37	3.97	25.8
1	5.22	0.67	0.32	7.22	0.35	3.82	23.3
2	5.45	0.71	0.35	7.02	0.34	3.87	23.5
4	4.89	0.65	0.31	6.95	0.31	3.85	24.8

and also where Mn can be toxic to plant growth, since these elements have detrimental effects on plant growth. If lime application is based on the exchangeable Al (Kamprath, 1967; 1970; Evans & Kamprath, 1970; Reeve & Sumner, 1970a; 1970b), which will also provide adequate Ca for plant growth, liming over and above the required amounts will cause some detrimental effects. In the present case, then, the high rates would only have meaning if the experiment was to be continued so as to neutralize any form of exchangeable Al that would arise from the non-exchangeable form through prolonged use of residual acid forming fertilizers such as ammonium sulfate. Surveys by Pearson and Adams (1967) and that of Fisher (1969) indicate that it is unnecessary to lime to pH 6.5 or above, since higher pH's may reduce the availability of P or induce trace element deficiencies. Robertson and Lipscomb (1970) found no consistent yield response to limestone over a 15-year period for corn and peanuts. This, they concluded, may have been due to the fact that plants were feeding on the relatively higher levels of Ca and Mg in the subsoil, or could utilize Ca that could not be extracted by extractants. Similar reports by Brans (1971) indicate that response to lime application was not found on maize and groundnut yields where Ca supply of the soil was 160 kg/ha, or if the pH of the soil is 5.3 or above.

Work in Ghana by Djokoto and Stephens (1961) and that of Ofori (1973) showed a positive effect to lime application, although the response was not sufficiently economical and was not recommended to farmers.

From the foliar composition data summarized in Table 9 and in Appendix Tables 15-20 it was observed that lime application and increased base saturation had no effect on the foliar composition of Ca, Mg, K, P, and Zn

of the maize seedlings sampled four weeks after planting, and the correlation coefficient values were -0.37, 0.25, 0.02, -0.02, -0.01, and -0.19 for N, P, Mg, Ca, K and Zn respectively (Table 10). This is in line with what Abruna et al. (1970) found for tobacco grown on Corozal Clay and Corozal Clay subsoil. A regression analysis was also done correlating the yield and soil properties in the present case, and it was found that there was no correlation between yield and any of the soil components studied (Table 11).

Minor season results are summarized in Tables 12 to 15. About a week after emergence, the maize seedlings were attacked by the "Army worms" which were identified by the entomologists as Sesemia botanephaga, and on October 24 spraying of maize with DIEDRIN commenced, the concentration being 3.7 cc of diedrin per litter of water. The spraying was at two week intervals, and after two sprayings, the plants were too mature for the worms to attack, and the process was discontinued.

There was severe bird damage to the grain once it had started to mature, and employing two men daily to scare the birds did not help.

Although there was damage to the grain, the little that was harvested seems to follow the same trend as the major season crop whereby there was an initial increase in grain yield at the lowest lime rate (1/2 t/ha), and that subsequent lime applications did not have greater effect on the yield. Since there was bird damage, it was decided to include the stover and cob weights in the data analysis, and these to followed the same trend as the grain yield, with an initial increase in weight to lime at the lowest lime rate, and that yield was depressed at the highest lime rate.

Table 10. Correlation Coefficients: Grain yield versus nutrient concentration in leaf-tissues sampled at 4-week old stage.

	Yield	N	P	Mg	Ca	K	Zn
Yield	1.000	-0.370	0.247	0.024	-0.022	-0.014	-0.190
N		1.000	0.266	0.158	-0.027	0.302	0.343
P			1.000	0.121	-0.059	0.478	0.224
Mg				1.000	0.700	0.102	-0.243
Ca					1.000	-0.065	-0.386
K						1.000	0.023
Zn							1.000

Table 11. Correlation coefficients: Grain yields versus exchangeable cations, P, and organic matter of the top soil samples.

	Y	P	Zn	Ca	Mg	K	B	EA	B.S.	O.M.
Y	1.000	0.052	0.187	-0.040	0.158	0.007	-0.029	0.001	-0.074	-0.162
P		1.000	0.694	0.835	0.479	0.377	0.855	-0.551	0.671	0.376
Zn			1.000	0.474	0.368	0.468	0.517	-0.227	0.331	0.393
Ca				1.000	0.418	0.226	0.995	-0.708	0.876	0.374
Mg					1.000	0.173	0.451	-0.032	0.156	0.342
K						1.000	0.254	-0.296	0.241	0.028
B							1.000	-0.675	0.856	0.412
EA								1.000	-0.913	0.150
B.S.									1.000	0.196
O.M.										1.000

Table 12. The effect of lime on the minor season maize grain yield, (tons/ha).

Treat/Rep	I	II	III	IV	V	VI	MEAN
Lime tons/ha	tons/ha						
0	0.79	0.66	0.92	0.92	0.66	0.66	0.77
1/2	0.53	0.92	0.92	1.05	0.79	0.79	0.83
1	1.19	0.66	0.66	0.79	0.79	0.66	0.79
2	0.79	0.79	0.92	0.66	0.92	0.66	0.79
4	0.92	1.05	0.66	1.05	0.79	0.66	0.86

ANOVA

Source	df	SS	MS	F
Treatment	4	0.03115	0.00779	0.27
Replicates	5	0.12269	0.02454	0.86
Error	20	0.56641	0.02832	
Total	29	0.72028		

Table 13. The effect of lime on the minor season cob yield-no grain (tons/ha).

Treat/Rep	I	II	III	IV	V	VI	MEAN
Lime tons/ha	tons/ha						
0	0.79	0.79	1.19	1.32	0.53	0.79	0.90
1/2	0.53	1.19	1.19	1.19	1.05	0.79	0.99
1	1.32	0.92	1.19	0.92	0.92	0.79	1.01
2	0.92	0.92	1.05	0.79	1.05	0.53	0.88
4	1.05	1.19	0.57	1.32	0.66	0.79	0.93

ANOVA

Source	df	SS	MS	F
Treatment	4	0.07642	0.01910	0.31
Replicates	5	0.45686	0.091372	1.52
Error	20	1.19554	0.059777	
Total	29	1.72882		

Table 14. The effect of lime on the minor season straw weight,
(tons/ha)

Treat/Rep	I	II	III	IV	V	VI	MEAN
Lime tons/ha	tons/ha						
0	4.61	3.30	3.43	4.35	2.37	2.64	3.45
1/2	3.43	3.82	4.09	4.48	3.69	3.43	3.82
1	4.09	3.56	3.82	4.61	3.82	3.30	3.87
2	3.16	4.35	4.75	3.96	3.96	3.30	3.91
4	2.90	3.82	3.96	3.96	3.16	3.30	3.52

ANOVA

Source	df	SS	MS	F
Treatment	4	1.1005	0.2751	1.13
Replicates	5	3.8883	0.7776	3.20
Error	20	4.8501	0.2425	
Total	29	9.8389		

Table 15. The effect of lime on the minor season trial dry weight-grain
+ cobs + straw (tons/ha).

Treat/Rep	I	II	III	IV	V	VI	MEAN
Lime tons/ha	tons/ha						
0	6.20	4.75	5.54	6.59	3.56	4.09	5.12
1/2	4.48	5.93	6.20	6.72	5.54	5.01	5.65
1	6.59	5.14	5.67	6.33	5.54	4.75	5.67
2	4.88	6.06	6.72	5.40	5.93	4.48	5.58
4	4.88	6.06	5.18	6.33	4.61	4.75	5.30

ANOVA

Source	df	SS	MS	F
Treatment	4	1.4028	0.3507	0.68
Replicates	5	8.7014	1.7403	3.41
Error	20	10.1864	0.5093	
Total	29	20.2906		

Table 16. Summary of the minor season results. (Means)- tons/ha

<u>Treatment</u>	<u>Grain</u>	<u>Cobs</u>	<u>Straw</u>	<u>Total</u>
0	0.77	0.90	3.45	5.12
1/2	0.84	0.99	3.82	5.65
1	0.79	1.01	3.87	5.67
2	0.79	0.88	3.91	5.58
4	0.86	0.93	3.52	5.31

The present work is in agreement with what has been reported in that high lime applications depress yield (Monteith & Sherman, 1963; Evans & Kamprath, 1970; Kamprath, 1970; 1971; 1972; Reeve & Sumner, 1970; Brams, 1971). These authors have indicated that lime should be applied to soils when it is necessary to neutralize aluminum and/or manganese which can be toxic to plants. Brams (1971) pointed out that the failure for response to lime in Sierra Leone may be due to the fact that there was adequate Ca in the soil for plant use.

Conclusions

Since there was a modest response to the first increment of lime and then a slight depression in yield at the highest lime rate, one would be led to conclude that the lime requirement for the Kumasi soil is low. One point to note in the present study is that there was a great variability in the soil properties, and this is attributed to various factors among which is the burning of brush on the spot after clearing the forest. Besides this, the uprooting of the forest brought some sub-surface horizon soils which are generally low in pH, organic matter and nutrients. Liming such a soil would result in either a good response or an overliming injury. Over and above, a newly cleared area would have a high pH, organic matter, and a good supply of nutrients for plant growth, so that a low lime rate would have more meaning in neutralizing the anticipated acidity which arises when acid residual fertilizers are used.

A careful study of the undisturbed top and sub-soils would give a better answer with regard the sub-soil infertility since it is the sub-soil infertility that seems to be limiting in the early stages of

clearing a new forest site. The purpose of the following greenhouse experiments was to investigate the effects of lime, phosphorus and zinc on maize growth, and a study of some of the soil properties was

IV. THE EFFECTS FROM OVERLIMING A HIGHLY WEATHERED SOIL

Introduction

In the temperate regions such soils as Mollisols and Alfisols require liming to a pH value of from 6.5 to 7.0. In many instances liming of most soils of the tropics to pH 7 does not result in much response in yield, and in some cases there may result a decrease in yield (Kamprath, 1970; Reeve & Sumner, 1970; Evans & Kamprath, 1970). This difference between Ultisols and Oxisols on the one hand and Mollisols and Alfisols on the other is the chemical and mineralogical properties. Kaolinite is generally the predominant clay mineral in the highly weathered acid soils, whereas Mollisols and Alfisols have a high reserve of weatherable minerals, which generally have no coating of hydroxy-Al and hydroxy-Fe which are proton donors (or OH acceptors).

In Hawaii, Monteith and Sherman (1963) found that Sudan grass grown on acid latosols responded to lime only if pH was brought to 5.5 whereas liming to pH 7 drastically reduced the yield. Reeve and Sumner (1970) reported that lime application should be up to the amount needed just to neutralize the exchangeable Al. Martini et al., (1974) advocated liming to just neutralize the exchangeable Al as suggested by Kamprath in his several papers (1967, 1970, & 1972), but liming to bring soil pH to neutrality requires very high rates because of the high pH-dependent charge in these soils. In their case, Martini et al., (1974) limed up to as high as 28 t/ha and yet there was no significant increase in soybean yield, and also there was no detrimental effect. Evans and Kamprath (1970) working with acid soils in the greenhouse obtained maximum soybean growth

when liming adjusted soil pH to 5.4-5.8. In order to reach neutrality in these soils required lime about 200% in quantities of the exchange soil acidity. They also mentioned that the amount of lime required to neutralize Al does not depend on the percentage Al-saturation but on the quantity of the Al. According to Pionke and Corey (1967), this may be due to the non-exchangeable Al which can only be brought into solution when the electrolyte concentration of the soil changes due to use of salts, for example fertilizers (Nye et al, 1961). This is in agreement with what Ofori (1973) reported in that fertilizers such as ammonium sulfate had a lowering effect on the soil pH. As Clark and Nichol (1966) suggested, organic matter formed insoluble Al-OM, which reduced solubility of Al through complex formation, and thus it is necessary to take into account both the pH and the solubility of Al in estimating the lime needs of soils with high organic matter.

In the present study, some of the effects of lime application on soil properties and maize growth are discussed. This includes a study of the amorphous materials, P chemistry, cation exchange capacity besides pH. A close study of the detrimental effect on the maize growth is also discussed.

Materials and Methods

A randomized complete block design was established with four replicates, three soils types, and five lime treatments. Top soil (0-15 cm) and subsoil (15-30 cm) passed through a 5 mm sieve were used as follows:

- a. Top soil placed in greenhouse pots (6 kg soil/pot);
- b. 6 kg of subsoil placed in pots; and
- c. 3 kg of top soil placed on top of the subsoil (3 kg).

Increments of Ca(OH)_2 were used at the rates of 0, 1, 2, 4, and 8 tons/ha in order to provide a wide range in acidity. The Ca(OH)_2 was thoroughly mixed with the top and sub-soils, except in (c) where the lime was added only to the top soil. At planting time all pots were given a basal treatment of N, P, and K at the rates of 40 kg, 45 kg, and 30 kg per hectare respectively in the form of ammonium sulfate, KH_2PO_4 , and KCl. After two weeks an additional 80 kg/ha N was added to the pots.

Composite 4 maize variety (*Zea mays* L.) was planted, 8 seeds per pot, and after the seedlings had attained a 5-leaf stage the seedlings were thinned to 4 plants per pot. Heights of plants were measured at the second, third, and fourth week after planting. The plants were harvested after four weeks of growth, dried at 70°C , weighed, and ground for analysis. The whole experiment was repeated two more times in the same pots without further lime treatment, except the basal applications which were repeated (N, P, and K) at the same rates.

i. Soil chemical analyses:

Soil samples taken from each pot during the third harvest and soils from each treatment were composited, dried, passed through a 2 mm sieve and stored in plastic bags for analyses. pH, exchangeable bases and acidity, and organic matter were determined as before (Chapter II). A study of the percentage Al saturation was also done as before. A fractionation procedure of Chang and Jackson as modified by Robarge (1971) was used for determining adsorbed P, aluminum P, iron P, and calcium P. The "active amorphous" materials were determined by the Tweneboah et al. (1967) procedure, and Al, Fe, and Si in solution were determined by the aluminon reagent,

orthophenanthroline reagent, and the molybdate blue methods respectively (Black, 1965).

ii. Tissue analyses:

Tissue analysis was done by the procedure as described by Greweling (Agron. Memio. 6622, 1966, Cornell Univ.). One gram oven dried samples were ashed at 550°C, then HNO_3 and HCl were used to complete oxidation of O.M. and to dehydrate silica, respectively. P in solution was determined colorimetrically; Ca, Mg, K, and Zn were determined by atomic absorption spectrophotometry, N by titration.

Results and Discussion

The Effect of Lime on Some Chemical Properties

1. The effect of lime on exchange properties:

Tables 17 and 18 summarizes some of the chemical properties affected by lime application, and it was observed that $\text{pH}_{\text{H}_2\text{O}}$ is higher than that measured in CaCl_2 and KCl , but that with the KCl , the pH rose drastically when 8 tons/ha lime was applied. Although this crossing was not observed when the soil was titrated at various concentrations of NaCl , it may mean that the Zero Point of Charge was not detected by the NaCl method.

The rise in pH is more rapid in the subsoil horizon than in the surface soil, and this may indicate that the lime requirements of these horizons follows the total exchange acidity and not the pH. Liming, then, should be based on the total acidity based on the exchange capacity in that soils with a higher exchange capacity have a bigger reservoir for the

Table 17 . Some soil chemical characteristics of the soil samples from the greenhouse lime experiment.

TREAT	pH			Ca	Mg	K	Σ Bases	E.A.	Σ Cations	% B.S.
Lime tons/ha	H ₂ O	CaCl ₂	KCl	me/100 g						
				<u>TOP SOIL</u>						
0	5.40	5.25	4.85	5.99	1.44	0.08	7.51	7	14.51	51.8
1	5.70	5.50	5.20	6.86	1.44	0.08	8.38	6	14.38	58.3
2	6.20	6.10	5.52	7.48	1.60	0.10	9.18	5	14.18	64.7
4	6.95	6.85	6.54	9.36	1.44	0.08	10.88	4	14.88	73.1
8	7.30	7.10	6.95	16.84	1.44	0.08	18.36	1	19.36	94.8
				<u>SUBSOIL</u>						
0	4.80	4.60	4.25	2.24	0.41	0.05	2.70	6	8.70	31.0
1	5.55	5.45	4.70	3.87	0.33	0.05	4.25	5	9.25	45.9
2	6.40	6.35	6.35	4.99	0.31	0.05	5.35	4	9.35	57.2
4	7.30	7.10	7.15	8.11	0.37	0.06	8.54	2	10.54	81.0
8	7.40	7.15	7.72	13.34	0.41	0.06	13.81	2	15.81	87.4

Table 18. The effect of lime application on 1N KCl extractable cations and pH.

and pH.						
Treat.	pH	Ca	Mg	Al	Σ Cations	
Ton/ha	KCl	CaCl ₂	me/100g			
			<u>Top Soil</u>			
0	4.8	5.2	6.00	1.52	0.14	7.66
1	5.2	5.5	7.45	1.52	-	8.97
2	5.5	6.1	8.45	1.45	-	9.90
4	6.5	6.8	9.00	1.16	-	10.16
8	7.0	7.1	10.05	0.95	-	11.00
			<u>Subsoil</u>			
0	4.2	4.6	21.0	0.40	0.31	2.80
1	4.7	5.4	3.70	0.30	-	4.00
2	6.4	6.4	5.00	0.30	-	5.30
4	7.2	7.1	6.00	0.16	-	6.16
8	7.7	7.2	6.45	0.16	-	6.61

exchange acidity at any one pH. Clark (1966) and Clark and Nichol (1966) have shown that there was no direct relationship between pH and either soluble or exchangeable Al in acid soils.

Although the clay content of the subsoil was greater than that of the surface soil, and thus assuming a greater reservoir for acidic cations, this does not seem to be the case. Since the top soil was more buffered than the subsoil, due to higher organic matter content of the surface horizons, this O.M. would contribute to total acidity, which means that it would take more lime to reach pH 7 for the surface soil than the subsoil. Keeney and Corey (1963) found a high correlation between O.M. content and lime requirement. Considering that O.M. contributes significantly toward titrable acidity or pH dependent charge (Reeve & Sumner, 1970), it is not surprising that lime requirement was highly correlated with O.M. resulting in prohibitively high lime requirement values for soils high in O.M. These results have been verified by various workers (Bhumbla & McLean, 1965; Evans & Kamprath, 1970; Pionke & Corey, 1967). Recent work by Amedee and Peech (1976a) shows that Al could continued to be extracted with successive KCl extractions, and the amount of Al extracted depended on the concentration of KCl.

Usually, Al-polymers are precipitated on clay surface and there is some Al complexed by organic matter, which are in non-exchangeable forms, whereas KCl usually extracts the exchangeable form, which exists primarily as $\text{Al}(\text{H}_2\text{O})_6^{3+}$ (Pionke & Corey, 1967). This may explain why in the present study liming the top soil did not result in a big change in pH, even though the pH of the top soil was already high. Also it is of use to

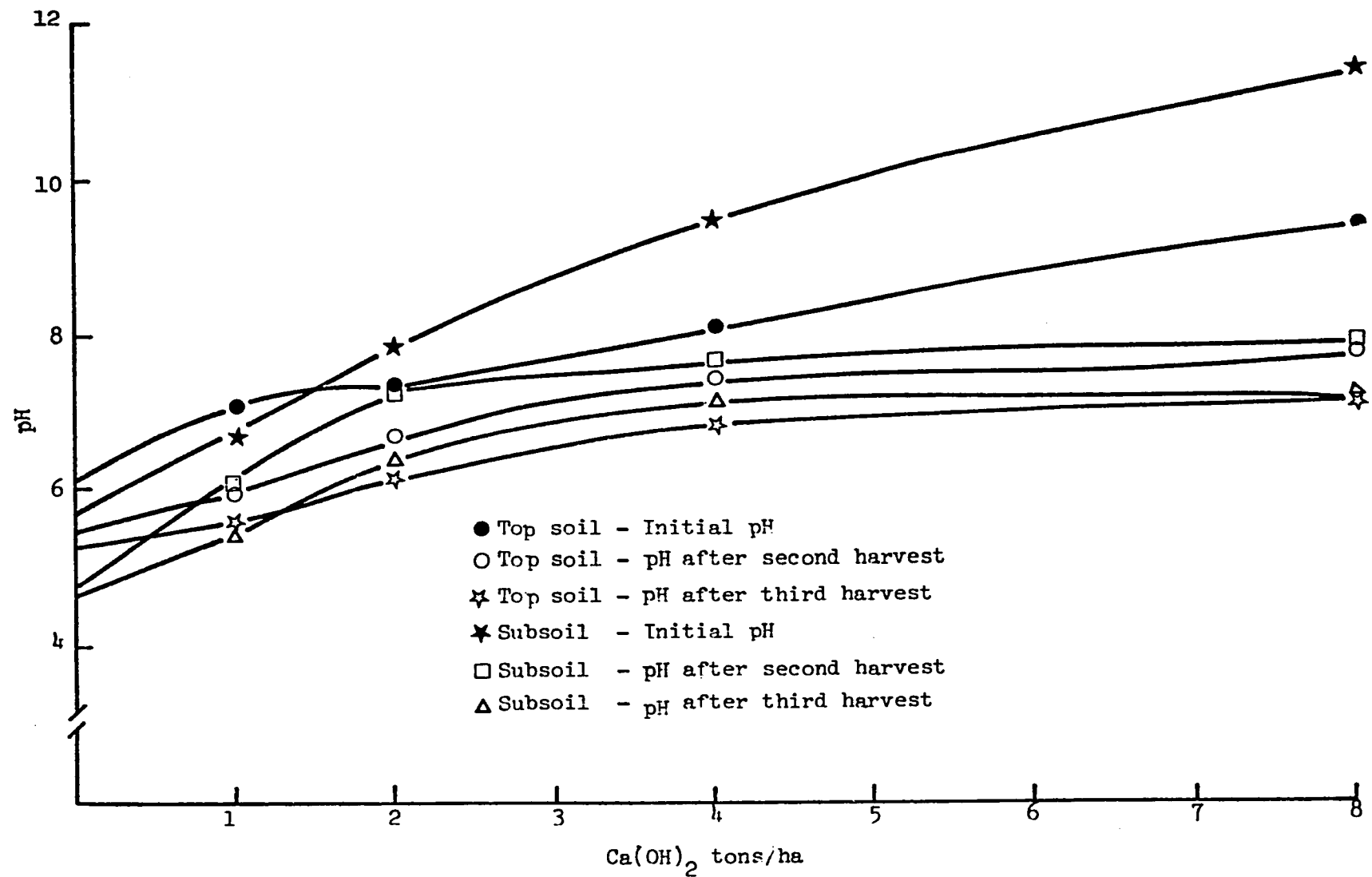


Figure 2. The effect of lime application ($\text{Ca}(\text{OH})_2$) on the pH at different times of soil sampling.

note that the neutralization of non-exchangeable form is relatively slow (Bhumbla & McLean, 1965) and that is why the pH in the present study rose fast when the subsoil was limed and pH measured the same day (Fig. 2).

The cation exchange capacity (C.E.C.) as estimated by the summation of exchangeable cations ($\sum \text{Cations}$) using $\text{N NH}_4\text{OAc pH 7}$ procedure and exchange acidity by $\text{BaCl}_2\text{-TEA}$ did not change much in both soils until when the pH was around neutral when the C.E.C. rose drastically. This change was due to increase in Ca content of the soils. As the pH gets into the neutral range, the C.E.C. estimated by summation increases (Black, 1965). Similar results were observed in the field lime experiment. In the subsoil, though, the increase in the sum of cations was slightly more gradual than the top soil, an indication that the subsoil is easily saturated on the exchange sites, or that the reaction between the lime and the soil is much slower than that of the top soil.

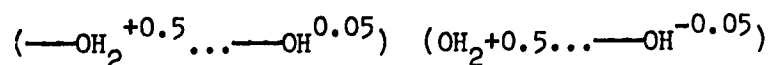
The effective C.E.C. of the soils also increased with the increased lime application, which is as expected. The effective C.E.C. was low in general, as was expected for highly weathered soils (Kamprath, 1970). A high saturation of Al leads to a low effective C.E.C., and the subsoil seemed to follow this theory. Kamprath (1970), in working with highly weathered soils found that raising pH above 5.2-5.4. resulted in a marked increase in the effective C.E.C. of the soils. This may have been due to ionization of H^+ ions from ferric and Al hydrous oxides accounting for a considerable portion of the pH dependent C.E.C. of these soils (Coleman et al., 1964). Yuan (1970) pointed out that although the reduction of Al

toxicity may well be the primary function of liming, the increase in C.E.C. by liming of the soil to a pH near neutrality would also be a means of improving the soil chemical conditions. This, he goes on to say, would maintain the effective control of the active Al form which is potentially soluble when acid forming fertilizers are used.

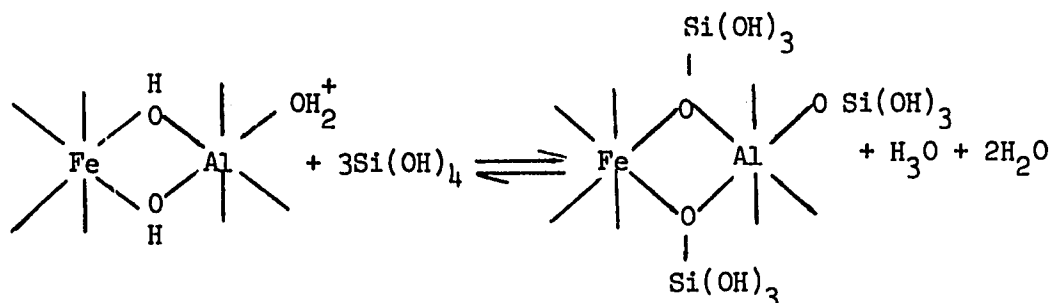
2. The effect of lime on amorphous material:

The analyses of "active" amorphous materials summarized in Table 19 show that generally in this soil there was more Al_2O_3 , Fe_2O_3 and SiO_2 extracted from the surface horizon than from the subsurface horizon. Whereas the Al_2O_3 remained fairly constant in the top soil, there was a gradual increase of SiO_2 with increased lime application which had an effect on the $\text{SiO}_2/\text{Al}_2\text{O}_3$. On the other hand there was an initial drop in Al_2O_3 in the subsoil at the lowest rates of liming; the Al_2O_3 increased with further liming. SiO_2 , though, was constantly increasing, thus the $\text{SiO}_2/\text{Al}_2\text{O}_3$.

The mechanism which controls the "active" Si as determined by the Tweneboah et al., (1967) procedure can only be speculated. It is reported in literature that Si in solution decreased with increased pH. Hingston and Raupach (1967) seem to give a good reason why Si decreases. Silicic acid is adsorbed by reaction with isoelectric edge pairs:



on the surface of aluminum hydroxide. The reaction between silicic acid and hydroxides could proceed as follows:



Thus increasing the pH from 4 to the isoelectric point ($\approx \text{pH} 9$) would increase the number of $(\text{OH}_2^{+0.05} \dots \text{OH}^{-0.05})$ groups on the aluminum hydroxide surface. McKeague and Cline (1963) reported that Si(OH)_4 could be removed from solution by adsorption onto solid surface, and that adsorption was pH-dependent, since adsorption increased throughout the reaction range pH 4 to pH 9. McKeague and Cline (1963c) mentioned that the mechanism by which alumina depresses the solubility of silica is the formation of hydrated aluminum oxide around the siliceous particles. Thus when the 0.5M CaCl_2 pH 1.5 is used, most of the silicic acid which had been adsorbed on the aluminum hydroxide surfaces will solubilize. From the work of Tweneboah et al. (1967) with various aluminum and iron oxides or hydroxides, clays, and soils reveals that the low Si/Al ratio suggests that most of the aluminum that dissolved came from the surface and not from the clay lattice. The treatment did not have any effect on the kaolinite used. When it came to the selectivity, the present work is in agreement with the work of Tweneboah et al. (1967) who found that in almost all soils, except one, the amount of aluminum was considerably greater than the amount of silicon and iron. The soil where silicon released exceeded

Table 19. 0.5M CaCl_2 pH 1.5 extractable "active" amorphous material, $\mu\text{g/g}$.

Treatment	SiO_2	Al_2O_3	Fe_2O_3	$\text{SiO}_2/\text{Al}_2\text{O}_3$
t/ha ^{1/}	<u>Top soil</u>			
0	631	2721	360	0.394
1	672	2645	344	0.431
2	802	2993	367	0.455
4	802	2645	360	0.514
8	1029	2872	379	0.607
	<u>Subsoil</u>			
0	436	2343	264	0.316
1	481	2071	239	0.394
2	505	2071	292	0.414
4	806	2373	349	0.577
8	888	2479	379	0.607

^{1/} Lime applied as $\text{Ca}(\text{OH})_2$

that of aluminum was the only calcareous soil, and the pH was sufficiently high to render aluminum hydroxides in the soil immobile and the formation of aluminum hydroxides unlikely. The work by Mughogho (1975) on some clay fractions of soils from Malawi came up with a similar results whereby the less weathered soils showed a high percentage of silicon as compared to Al which was removed by the 0.5M CaCl_2 pH 1.5 extractants, with $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios between 1.7-2.0. In the present case, since these soils were more weathered, the procedure was the right one to use for these soils. Liming slightly changed the reaction products and the increase in Si relative to Al may be a kinetic one. Since adding lime might have caused some micro-variabilities in the soil, with pH's going up to or over pH 9.2, there would have been some solubilization of Si, and that with time the pH decreased, but the silicon in solution might have been adsorbed by aluminum hydroxides, and the 0.5M CaCl_2 pH 1.5 extracted the Al and the Si.

The amount of Fe_2O_3 extracted by the Tweneboah et al. (1967) procedure did not vary much in the surface horizon, although it slightly increased in the subsoil with increased pH. The initial lime application (1 t/ha) depressed the amount of Fe in solution then subsequent treatments increased Fe_2O_3 , whereas the Al_2O_3 dissolved in subsoil did not change significantly; it can be speculated that the SiO_2 dissolved may be associated more with Fe than Al, although the percentage increase in Si was not the same as that of Fe. However, the failure to correlate between the amount of Fe and Si dissolved in the top soil does not seem to agree with the speculation. The whole process, then, may involve the kinetics of Si dissolution and adsorption than anything else when soils are limed.

3. The effect of lime on the inorganic phosphorus fractions:

From the fractionation results, summarized in Table 20 and Appendix

Table 20. Fractionation of inorganic phosphates from the greenhouse lime experiment.

Treatment	Adsorb-P	Al-P	Fe-P	Ca-P	$\sum P_I$
	ug/g				
T ₀	34.09	13.64	19.76	24.62	92.11
T ₁	34.85	14.64	17.02	30.78	97.29
T ₂	37.50	16.42	12.46	38.00	104.38
T ₄	42.42	14.14	8.51	39.82	104.89
T ₈	45.08	16.06	4.21	42.56	107.91
S ₀	38.64	10.86	34.96	5.59	90.05
S ₁	32.96	10.36	30.54	9.34	83.20
S ₂	42.42	14.90	32.98	20.90	111.20
S ₄	43.94	15.76	17.32	43.46	120.48
S ₈	43.03	21.16	7.09	46.51	127.79

Fractionation of inorganic phosphates from the soil that were untreated.

	Adsorb-P	Al-P	Fe-P	Ca-P	$\sum P_I$
Top soil	13.2	5.1	9.2	19.9	47.4
Subsoil	4.5	2.0	8.6	3.0	18.1

Table 21. Relationship between applied P and soil-P fractions on soil samples from the greenhouse lime experiment.

P-fraction	Correlation coefficient	Regression equation
<u>Top Soil</u>		
Adsorbed-P	0.962	$Y=34.41 + 1.459X$
Aluminum-P	0.511	$Y=14.39 + 0.196X$
Iron-P	-0.959	$Y=18.09 - 1.904X$
Calcium-P	0.854	$Y=29.22 + 1.980X$
$\sum P_I$	0.847	$Y=96.13 + 1.729X$
<u>Subsoil</u>		
Adsorbed-P	0.908	$Y=35.84 + 2.128X$
Aluminum-P	0.965	$Y=10.61 + 1.334X$
Iron-P	-0.966	$Y=35.54 + 3.654X$
Calcium-P	0.914	$Y= 8.68 + 5.492X$
$\sum P_I$	0.869	$Y=90.67 + 5.292X$

Figures 1-5, the unphosphated soil, the order in magnitude of the P fractions is: Ca-P>adsorbed-P>Fe-P>Al-P for the surface soil and Fe-P>adsorbed-P>Ca-P>Al-P for the subsoil, whereas the phosphated soils are in the order of adsorbed-P>Ca-P>Fe-P>Al-P for the surface soil and adsorbed-P>Fe-P>Al-P>Ca-P for the subsoil. The proportion of the sodium bicarbonate extractable (adsorbed-P) in the soils under study was much less than the values reported for some soils of Malawi (Mughogho, 1975) and same order as those of Weaver et al. (1975) for the highly weathered soils of Puerto Rico. The greater amounts of Ca-P in the surface soil compared to low levels in the subsoil is an indication that there is a greater amount of Ca in the surface soil to account for the increased Ca-P. It is generally agreed that in acid soils, oxides of iron and aluminum play a predominant role in the phosphorus-soil reaction. Since the subsoil is more acid than the surface soil, this seems to be in agreement with what is reported in that Ca-P is reverted to Al-P and Fe-P with weathering. The recycling of nutrients including calcium makes the top soil rich in Ca, and this coupled with the complexing of Al and Fe with O.M. in this horizon makes the Ca-P dominant form of inorganic P fractions. In other words, the shifting between aluminum and calcium phosphates may be attributed to higher activities of these ions. At very acid pH's it would be expected that the calcium and aluminum phosphates would ultimately change to iron phosphate

Enwezor and Moore (1966) for example, found that iron phosphate accounted for over half of the total extractable P for all profiles, whereas Al- and Ca-P were relatively low. Therefore, the fact that the 0.1N NaOH extracts

more Fe-P in an acid soil would support the theory that with weathering, the Al-P and Ca-P are converted to the Fe-P, the kinetics of which is believed to be very slow (Chang & Jackson, 1958).

In the phosphated soil, the increase in the adsorbed-P in relation to the other fractions indicated that these soils did not have a high fixing capacity for P, although there is an increase of P in all fractions.

Liming increased the adsorbed-P slightly in the surface soil and significantly in the sub-soil, and it was true for Al-P too. In fact the Al-P almost doubled with the highest lime rate (8 t/ha) as compared to the check. The increase in Ca-P also followed a similar trend to that of adsorbed-P in that the top soil there was a slight increase in this fraction whereas in the subsoil there was a tremendous increase in Ca-P from 5.59 ppm to 46.5 ppm. This may have been due to differences in the buffering capacity of these soils. This was also explained for the pH versus $\text{Ca}(\text{OH})_2$ added, where initially the pH in the surface soil was higher than in the subsoil, but as lime was added the pH increased in the subsoil much more than the top soil.

Liming, though, decreased the Fe-P fraction, the effect being greatest at the highest lime rates (4 and 8 t/ha). This is explained in Figure 3. At very low pH's FePO_4 is less soluble than AlPO_4 and increasing the pH increases the solubility of FePO_4 much more than AlPO_4 , although both increased. This explains why with the present work, the iron phosphate was highly soluble, and thus was readsorbed as either Al-P or Ca-P. Lime may change the chemical characteristic of the soil to the extent that NaHCO_3

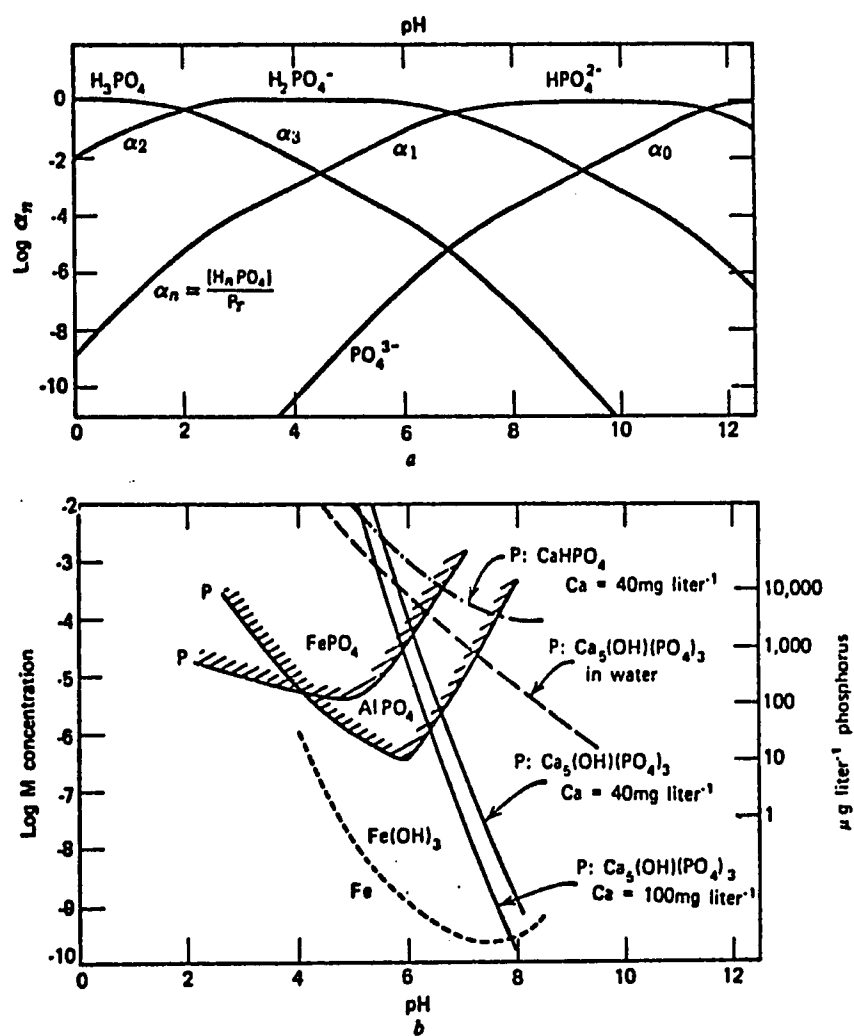
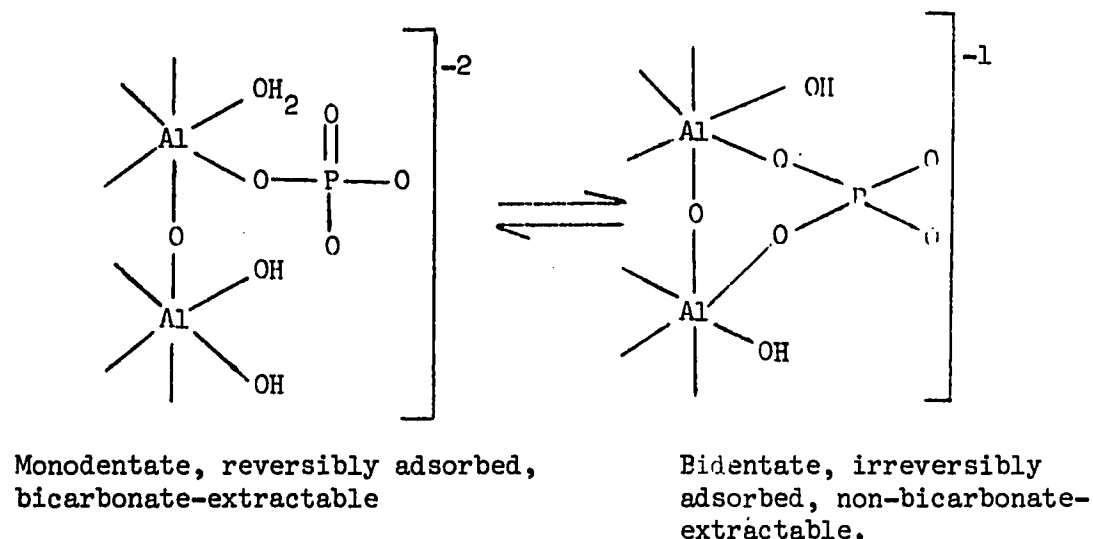


Figure 3. Effect of pH on various phosphorus forms. (Stumm and Morgan, 1970)

or NH_4F extracts some phosphated iron-P. Bromefield, (1967), working with soils, aluminum oxides, and iron oxides which were phosphated, found that during fractionation the crystalline iron phosphate was readily distinguished from crystalline Al-P, and this was attributed to much lower solubility of iron phosphate in NH_4F . On the other hand, other iron phosphates, phosphated hematites for example, released much of their phosphate during NH_4F extraction which could be confused with Al-P and phosphated Al oxides. Yuan et al. (1960) found that some Fe phosphates may be more soluble in NH_4F than crystalline phosphates, thus agreeing with Bromfield (1967). In conclusion, then, one could say that since ammonium fluoride does not readily discriminate between phosphated oxides of Fe and Al, it is unwise to assume that this reagent dissolves mainly Al bound phosphate from soils fertilized with phosphate. In fertilized soils it is probable that some of the phosphate is present as amorphous iron and aluminum phosphates sorbed on oxides of iron and aluminum.

It also was found that the amount of NaHCO_3 extractable P was correlated with the amount of SiO_2 extracted by 0.5 M CaCl_2 of pH 1.5 or the $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio. Since increasing pH results in increased Si adsorption (Hingston & Raupach (1967), this would saturate the exchange sites for P adsorption, thus rendering it more available.

Hingston et al. (1974) explained that P may be adsorbed onto Fe or Al oxide surfaces as monodentate or bidentate Fe- or Al-P. They went on to explain that because of the increase in entropy that probably results from ring formation, the bidentate complex is probably more stable than the



monodentate complex. And since silica or monosilicic acid can also be adsorbed by Al and Fe oxides in a similar manner to that of P, it would seem plausible that an increased amount of adsorbed silica would limit the potential adsorption sites in which P could form the bidentate complex. It, therefore, confirms the suggestion by Hingston and Raupach (1967) that increasing pH will result in increased silicon adsorption. Correlation studies indicate that there is a good correlation between active SiO_2 extracted by Tweneboah et al. (1967) procedure and the amount of P desorbed by the sodium bicarbonate procedure.

The effect of lime and P application on subsoil pH, O.M. and P in the
Top/sub-soil treatments

The results in Table 22 show the differences in soil properties as influenced by lime application. It can be pointed out that in the top of the Top/sub the pH increased with increased $\text{Ca}(\text{OH})_2$ application whereas the subsoil pH does not increase, which may indicate that liming has little or no effect on the subsoil. The field results also showed similar

Table 22 . Organic matter, adsorbed-P, and pH of the soils from the Lime Experiment.

Treatment	O.M. %	P ppm	pH _{H₂O}	pH _{CaCl₂}
T ₀	3.4	14.03	5.40	5.25
T ₁	3.4	17.10	5.70	5.50
T ₂	3.6	17.18	6.20	6.10
T ₄	3.3	19.79	6.95	6.85
T ₈	3.4	23.31	7.30	7.10
S ₀	1.5	15.95	4.80	4.60
S ₁	1.2	16.26	5.55	5.45
S ₂	1.1	18.86	6.40	6.35
S ₄	1.1	17.48	7.30	7.10
S ₈	0.9	23.70	7.40	7.15
T/S ₀ -Top	3.4	26.84	5.10	4.95
T/S ₁ -Top	3.3	30.52	5.50	5.30
T/S ₂ -Top	3.4	26.46	5.85	5.70
T/S ₄ -Top	3.4	31.82	6.45	6.35
T/S ₈ -Top	3.3	39.11	7.15	6.90
T/S ₀ -Sub	1.1	1.76	5.75	5.35
T/S ₁ -Sub	1.1	1.92	5.70	5.50
T/S ₂ -Sub	1.2	1.61	5.75	5.45
T/S ₄ -Sub	1.1	1.46	5.80	5.50
T/S ₈ -Sub	1.1	1.60	5.95	5.90

results. Work of Djokoto and Stephens (1961b) is in agreement with the present work in that they found no increased leaching of Ca into the subsoil even eight years after liming. Some work by Grant (1970) on acid soils in Rhodesia showed that lime was lost by leaching during the first two seasons after liming, but that the proportion varied from 10 to 60 percent according to soil and ambient conditions. In the present case, even though ammonium sulfate was applied, it did not seem to have much effect of causing much leaching despite the fact that pH decreased with time. Amedee and Peech, (1975) defined calcium leaching losses and they pointed out that it is dependent on the degree of Ca^{++} saturation. The decreased pH after liming and growing maize in the present work was due to the residually acid ammonium sulfate that was used, and that most of the $\text{Ca}(\text{OH})_2$ might have reacted with the exchange acidity (Fig. 2).

Just as the pH, P application did not seem to have much effect on the subsoil P, which may indicate that there was not much leaching in P. In other words, most of the P is bound in the top soil. One of the contributing factors to failure of the Ca from leaching may be that some of it is precipitated as calcium phosphate.

The Effect of Lime on Maize Growth

Maize yield

In the first planting, it was observed that two weeks after planting there were some signs of Zn deficiency symptoms, more especially in the limed soils. These symptoms were severe at 2-8, 4 and 8, and 8 tons/ha lime in the subsoil, top soil, and top/sub-soil treatments respectively.

The symptoms first started as streaks, then bleach, and in the final stage, towards harvest (28-days duration), some plants were dying. Even if P was applied at 45 kg/ha there were some P deficiency symptoms in some treatments, more especially in the subsoil.

The second planting also showed some Zn deficiency symptoms which appeared only in the subsoil at the highest lime treatment (8 t/ha). The symptoms were typical, that is the interveinal bleaching which appeared on both sides of the midrib, but the leaf margin and the tips of the leaves were still green. In severe cases, the young leaves in the whorl were bleached. Some minor cases vanished with time, an indication that with increased root development the plants were able to utilize the Zn in the soil.

The third planting showed similar results in that at harvest there were severe Zn deficiency symptoms in the maize growing in the subsoil that received the highest lime application (8 t/ha). There were a few plants in the 4 t/ha lime treatment that also showed some deficiency symptoms, although the plants were not as stunted in growth as those that received 8 t/ha lime. In this last planting, there were signs of K deficiency symptoms in the plants that were vigorous and that did not show any signs of Zn deficiencies (scorching, dying of the tips and margins of the leaves), and the symptoms were severe in the top/sub-soil treatments.

Table 23 and Appendix Tables 21-30 show some of the yield data. Lime caused a great depression in yield in both the subsoil and the top soil lime treatments in the first planting ($P=0.01$), and there was no signi-

Table 23 . The effects of lime treatments on maize growth, g/pot.

Treat	First harvest			Second harvest			Third harvest		
t/ha	Top	Sub	Top/su	Top	Sub	Top/su	Top	Sub	Top/su
0	14.45	8.48	12.30	14.90	11.34	14.25	14.72	12.72	15.95
1	13.45	7.15	12.35	14.88	11.32	14.55	16.88	13.55	14.28
2	12.75	6.42	11.05	15.85	10.95	14.85	15.10	12.90	16.08
4	10.90	4.35	10.00	15.10	8.95	14.80	13.08	9.90	14.80
8	8.10	2.40	10.98	18.62	4.88	14.50	14.45	5.58	12.65

ficant difference in the top/sub-soil lime treatments. This may be due to the fact that the roots in the top/sub-soil treatments had the sub-soil unlimed and that whatever imbalance in nutrients that could be caused in the top soil due to liming was alleviate since roots could utilize some subsoil nutrients.

On the other hand, in the second planting the top soil and the top/sub-soil treatments did not show any sign of yield depression due to lime application, and this may be attributed to the fact that in the top soil, most of the lime had reacted with the soil, and thus nutrient imbalances reduced. The subsoil still showed a depression in the maize growth, and this is due to the fact that the pH was still high, and thus caused some nutrient imbalance, since the soil is less buffered.

In the third planting there was an initial increase in maize yield at the lowest lime rate in the top soil, and that there was a depression in yield at the highest lime rates. The subsoil, though, continued to show the same trend in that lime depressed yield all the way, with the greatest decrease at the highest lime rate.

Nutrient uptake

It is important to note that during the first planting (4-week duration) here was a rapid increase in calcium uptake by the plants with increased in Ca(OH)_2 in the subsoil but the uptake was reduced at the highest lime rate (8 t/ha). The lowest Ca uptake at the highest lime rate may have been due to nutrient imbalance which caused the plants not to be efficient in utilizing other nutrients such as P or trace elements. The other two soil treatments did not show a big difference, but there was a gradual increase in Ca uptake (Tables 24-26).

Table 24. The effect of lime application on nutrient uptake during the first harvest,

<u>TOP SOIL TREATMENTS</u>						
<u>Treat</u> (t/ha)	<u>Yield</u> (g/pot)	<u>P</u>	<u>Ca</u>	<u>Mg</u> Mg/pot	<u>K</u>	<u>Zn</u>
<u>Rep I</u>						
0	14.10	32.4	71.9	49.4	691	0.78
1	12.25	33.1	79.6	56.4	666	0.71
2	12.30	29.5	80.0	52.0	597	0.62
4	10.60	30.7	93.3	53.0	577	0.52
8	7.05	24.0	72.6	35.2	402	0.31
<u>Rep II</u>						
0	14.80	34.0	71.0	57.7	684	0.74
1	14.65	32.2	71.3	49.8	718	0.66
2	13.20	30.4	70.0	51.5	634	0.59
4	11.25	28.1	79.9	50.6	585	0.53
8	9.15	34.8	97.0	45.8	540	0.40
<u>SUBSOIL TREATMENTS</u>						
<u>Rep I</u>						
0	8.80	14.1	83.6	48.4	128	0.77
1	6.65	13.3	79.8	46.6	128	0.31
2	6.65	10.6	99.8	50.5	100	0.28
4	3.90	7.8	73.7	29.2	96	0.43
8	2.20	3.1	40.5	12.1	52	0.19
<u>Rep II</u>						
0	8.15	12.2	61.9	44.8	137	0.27
1	7.65	13.8	72.7	43.6	147	0.20
2	6.20	13.0	94.9	49.6	124	0.33
4	4.80	8.6	87.8	33.6	127	0.21
8	2.60	3.4	53.0	14.3	66	0.22
<u>TOP/SUB SOIL TREATMENTS</u>						
<u>Rep I</u>						
0	12.00	31.2	85.2	60.0	492	0.54
1	11.45	25.2	74.4	45.8	449	0.45
2	9.70	25.2	82.4	53.4	457	0.51
4	9.50	30.4	90.2	52.2	466	0.48
8	11.05	25.4	88.4	55.2	473	0.49
<u>Rep II</u>						
0	12.60	29.0	73.1	63.0	435	0.64
1	13.25	31.8	71.2	57.0	477	0.64
2	12.40	29.8	71.9	53.3	476	0.52
4	11.70	30.4	83.1	56.2	468	0.41
8	9.05	28.1	93.2	49.8	443	0.50

Table 25. The effect of lime application on nutrient uptake during the second harvest.

<u>TOP SOIL TREATMENTS</u>						
Treat (T/ha)	Yield (g/pot)	P	Ca	Mg Mg/pot	K	Zn
<u>Rep I</u>						
0	15.60	48.4	90	86	499	0.75
1	15.05	52.7	90	82	542	0.80
2	15.85	52.3	112	119	571	0.87
4	17.00	52.7	136	102	728	0.78
8	16.95	52.5	144	117	651	0.78
<u>Rep II</u>						
0	14.20	59.6	88	96	554	1.04
1	14.70	51.4	88	74	532	1.07
2	15.85	53.9	116	92	618	1.20
4	13.20	40.9	98	76	515	0.82
8	20.30	65.0	152	126	751	0.95
<u>SUBSOIL TREATMENTS</u>						
<u>Rep I</u>						
0	11.40	37.6	74	51	302	0.52
1	11.50	35.6	94	63	269	1.15
2	9.75	36.1	91	54	278	0.55
4	8.75	46.4	114	66	267	0.67
8	4.20	31.5	71	27	214	0.27
<u>Rep II</u>						
0	11.35	36.3	74	49	329	0.48
1	11.15	37.9	95	59	292	0.72
2	12.15	43.7	119	68	311	0.75
4	9.15	47.6	114	59	299	0.39
8	5.55	19.4	116	38	246	0.41
<u>TOP/SUB SOIL TREATMENTS</u>						
<u>Rep I</u>						
0	14.35	53.1	112	86	376	0.86
1	14.85	54.9	96	89	407	0.83
2	14.60	54.0	95	106	394	0.88
4	14.90	50.7	104	109	372	1.06
8	14.45	46.2	104	116	361	1.30
<u>Rep II</u>						
0	14.50	56.6	99	102	392	0.75
1	14.25	59.8	107	88	453	0.76
2	15.10	51.3	103	106	396	0.98
4	14.70	51.4	132	103	403	1.04
8	14.55	46.6	135	109	399	0.71

Table 26. The effect of lime application on nutrient uptake during the third harvest.

<u>TOP SOIL TREATMENTS</u>						
Treat (t/ha)	Yield (g/pot)	P	Ca	Mg Mg/pot	K	Zn
<u>Rep I</u>						
0	14.75	59.0	125	130	386	0.66
1	17.15	61.7	146	129	406	0.57
2	14.80	54.8	126	111	405	0.52
4	13.15	47.3	129	108	360	0.45
8	14.70	51.4	118	103	397	0.47
<u>Rep II</u>						
0	14.70	57.3	106	118	368	0.62
1	16.60	61.4	111	126	374	0.63
2	15.40	58.5	128	122	394	0.57
4	13.00	55.9	120	103	390	0.61
8	14.15	49.5	149	119	389	0.66
<u>SUBSOIL TREATMENTS</u>						
<u>Rep I</u>						
0	12.90	47.7	94	50	354	0.49
1	13.55	51.5	108	58	304	0.43
2	12.90	52.9	103	55	379	0.54
4	11.05	49.7	123	63	298	0.26
8	4.25	38.7	66	28	254	0.17
<u>Rep II</u>						
0	12.55	45.2	107	83	339	0.63
1	13.55	55.6	112	76	355	0.77
2	12.90	50.3	112	70	322	0.46
4	8.75	60.4	116	53	324	0.38
9	6.90	62.8	110	52	331	0.21
<u>TOP/SUB SOIL TREATMENTS</u>						
<u>Rep I</u>						
0	15.80	74.3	107	111	333	0.52
1	14.15	69.3	106	113	354	0.45
2	16.25	68.2	102	107	325	0.52
4	14.50	62.4	102	109	310	0.48
8	12.25	46.6	113	98	314	0.31
<u>Rep II</u>						
0	16.10	75.7	113	121	370	0.61
1	14.40	70.6	115	109	331	0.55
2	15.90	71.6	127	132	350	0.60
4	15.10	74.0	127	119	378	0.50
8	13.05	57.4	124	103	326	0.40

The same trend seems to be repeated in the second planting whereby the subsoil showed a rapid increase in Ca uptake with the initial lime treatment and subsequently dropping at the highest rates. Again in the other soil treatments, the increase in Ca uptake was gradual at first, and leveled off for the top/sub-soil treatments. In the third harvest, however, all soils initially did not show any big difference, and whereas both the top and top/sub-soil treatments leveled off, the subsoil showed a depression in yield with increased lime application. This, again proves that the detrimental effect of high lime rates was greater in the less buffered soil than the well buffered top soil.

The same can be said of P uptake in that whereas there was not much difference in the uptake of P in the top and top/sub-soils, there was a great depression in P uptake in the subsoil when high lime rates were applied. This is in agreement with other studies. Kamprath, (1970, 1971) points out that plant growth was decreased and plants exhibited P deficiencies when soils were limed above pH 7. No reduction in growth was obtained, he adds, when the soil that did not respond to P fertilization was limed to pH 7. Fox et al. (1964) found that liming an aluminous ferruginous latosol to pH 6.1 increased uptake of fertilizer P but liming to pH 7 markedly decreased P uptake by sorghum and DESMODIUM INTORTUM, but that they did not get this marked decrease at pH 7 with humic ferruginous latosol.

A possible explanation given by Kamprath (1971) could be strength of P adsorption by soils in that where P is bound quite strongly a high concentration of Ca ions could reduce the P in solution to very low levels by formation of Ca phosphates. Thus where P is not bound very tightly a

sufficient concentration of P could be maintained. This seems plausible because with subsequent P application, the P uptake in the subsoil treatments increased during the second and third plantings, an indication that P was limiting in the subsoil.

Studies on Zn uptake indicate that in the top and subsoils there was a decreased Zn uptake with increased lime application in the first planting, and subsequent planting still showed a decreased Zn uptake in the subsoil. On the other hand, the top/sub-soil only showed a decreased Zn uptake in the third planting with increased lime application. This clearly shows that liming of soils with low native supply of Zn to high pH's will reduce the availability of Zn and thus very likely induce deficiencies, more especially if intensive cropping is to be carried out (Kamprath, 1971).

Conclusions

From the results, it can be concluded that the effect of excess lime applications was to depress the yield of maize in the greenhouse, and that the effect was accentuated when the soil has a low buffering capacity, such as the subsoil. The present work is in agreement with what has been reported in that lime applications of the Ultisols and Oxisols would depress yield (Monteith & Sherman, 1963; Evans & Kamprath, 1970; Kamprath, 1970, 1971, 1972; Reeve & Sumner, 1970). Lime should be applied to soils when it is necessary to neutralize Al and/or Mn which can be toxic to plants.

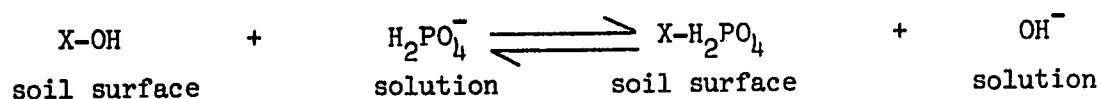
Overliming hazard is not reliably predictable since there are many factors controlling the acidity. Soils with high organic matter and CEC, even though they show a low intensity factor for acidity, may have a high reservoir for acidity, and thus may require high lime rates. This is reflected in the top soil treatments in the present study in that even though the pH was already high initially, there was not as much effect on

yield depression as when the subsoil, with low CEC, organic matter and pH was limed. The volume limed will also influence nutrient uptake. The top/sub-soil showed little or no yield depression due to overliming since the subsoil of the top/sub-soil was not limed, and thus roots could survey the subsoil for nutrients rendered unavailable in the limed top soil. Under field conditions one would expect little depression in yield since the volume of unreacted soil is greater. In any case, the most effective method for lime experiments in these soils is small applications at a time, and this would be more economical and less wasteful. Over and above, the peasant farmer is not willing to invest in high lime rates since liming materials in Ghana are very expensive (approximately \$4.00/50 kg of calcium hydroxide).

V. THE EFFECT OF LIME AND PHOSPHORUS ON SOME SOIL PROPERTIES AND MAIZE GROWTH

Introduction

Soils have been known to retain applied phosphorus, and that the "fixing" capacity of the soil depends on several factors which include low pH, high Al and Fe oxides and hydroxides, and high clay contents. Dean and Rubins (1947) postulated that through anion exchange mechanism, P would be fixed in the clay minerals and/or hydrous oxide:



From this, one would conclude that liming acid soils would improve P availability. There has been a lot of controversy over the validity of this assumption. Woodruff and Kamprath (1965) found that liming increased the efficiency of fertilizer P on acid soils that had an appreciable amount of exchangeable Al. Optimum levels for liming improved solubility of fertilizer P was between pH 5 and 6 in Hawaii (Fox et al., 1962). Later Fox et al. (1964) reported some results where when pH of acid aluminous soils was adjusted to 7, P uptake was drastically decreased. And they concluded that excess calcium at the root surfaces may have precipitated phosphorus.

Another common belief is that P concentrations increase after liming an acid soil in that when strengite and variscite are present, liming hydrolyzes these compounds in the soil and releases phosphate ions to soil

solution (Amarasiri & Olsen, 1973). In their results, Amarasiri and Olsen found that for any level of phosphorus, liming decreased soluble and labile P until the pH reached about 6.5, and they attributed the adsorption of P by freshly precipitated Fe and Al hydroxides which caused the greater inactivation of added phosphorus in the limed soils. In their experiment with rye and millet they found percent P in plants increased with liming at lower levels and decreased at higher rates.

Several authors have reported that rates of lime which neutralize exchangeable Al would result in more efficient uptake of P from Ultisols and Oxisols (Fox et al., 1964; Woodruff & Kamprath, 1965; Reeve & Sumner, 1970). A possible explanation, Kamprath (1971) adds, for these results could be the strength of adsorption by the soil in that where P is bound quite strongly a high concentration of Ca ions could reduce the P in soil solution to very low levels by formation of calcium phosphates. On the other hand where P is not bound tightly a sufficient concentration of P could be maintained.

In general, all the field sites where the lime and P experiments were laid showed P deficiency symptoms in the early stages, purpling of the leaves and stunted growth, and the effects were more accentuated by exposing the subsurface soils to the surface. These symptoms, though vanished gradually with time; but where P was not added, there was delayed maturity. To evaluate this observation, a greenhouse lime and phosphorus experiment was laid to observe the effects of the combination of lime and high P applications on both the growth of maize and soil properties.

Materials and Methods

For this experiment only the top- and sub-soils were used, each in a separate pot. Rates were 0 and 8 t/ha lime as Ca(OH)_2 and 0, 45, 90, and 180 kg/ha P as KH_2PO_4 were applied. Basal treatments were as in the earlier greenhouse lime experiment. Duration of each growth period of the experiment was 28 days. The experiment was repeated once more without any further application of lime or P, but that N and K were applied as basal nutrients. This study was undertaken to check if P application would alleviate the poor growth that results from over-liming the top or subsoils. Therefore, an attempt was made to study the effects of lime and P on some soil properties and on maize yield.

Soil chemical properties:

Soil samples were taken at the end of the second planting period, and samples from each treatment were composited, and the following analyses were done:

1. Amorphous materials were determined as in the first lime (greenhouse) experiment;
2. P-fractionation studies similar to those in the greenhouse lime experiment were carried out;
3. Correlation studies between added P and inorganic fractions and maize growth were made.

Plant growth:

Maize yields were measured at the end of each harvest period. Tissue analysis was done on oven dry samples as before, (Chapters III & IV).

Results and Discussion

The effect lime and phosphorus on the "active" amorphous materials.

In phosphorus retention studies it has been shown that amorphous compounds exhibit a high power of phosphorus adsorption and a low degree of availability (Cloos et al., 1968). The sorption of phosphorus onto clay minerals appears to involve not only the chemical bonding of the anions to positively charged edges of the clays but also of substitution of the phosphates for silicate in the clay structure.

Results in the present study (Table 27) show that lime application increased the amount of SiO_2 extracted by acid CaCl_2 and the possible mechanisms for the reactions has already been discussed in the greenhouse lime experiment. There seems to be no general trend of the behavior of SiO_2 or Al and Fe with different P rates. Saunders (1965) pointed out that phosphate adsorption and availability levels in allophane containing volcanic ash depends on the degree of silication of the amorphous compounds in that P adsorption decreases and P availability increases with increasing silicon content. Vice versa, increasing P application would affect Si adsorption in that P would fill the adsorption sites for Si, thus render it more soluble. Thus, it is speculated that in the present case, soluble Si would have increased with increased P application. This Si can either be absorbed by the plants, or leached, thus reducing the amount that can be adsorbed by Al/Fe oxides or hydroxides as suggested earlier. In the present case, since the acid CaCl_2 extracts Si associated with Al and/or Fe, this would mean that all the SiO_2 adsorbed on the amorphous Al or Fe

Table 27. 0.5M CaCl₂ pH 1.5 extractable "active" amorphous material, ug/g.

Treatment <u>1/</u>	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂ /Al ₂ O ₃
<u>Top Soil</u>				
L ₀ P ₀	558	2670	485	0.355
L ₀ P ₁	571	2594	460	0.373
L ₀ P ₂	625	2570	460	0.412
L ₀ P ₄	513	2594	496	0.336
L ₈ P ₀	794	2594	508	0.519
L ₈ P ₁	804	2745	496	0.497
L ₈ P ₂	794	2745	519	0.490
L ₈ P ₄	794	2745	525	0.490
<u>Subsoil</u>				
L ₀ P ₀	569	2318	339	0.416
L ₀ P ₁	528	2318	350	0.387
L ₀ P ₂	511	2418	350	0.358
L ₀ P ₄	419	2394	403	0.304
L ₈ P ₀	1063	2745	479	0.657
L ₈ P ₁	866	2670	479	0.550
L ₈ P ₂	883	2621	496	0.472
L ₈ P ₄	941	2645	466	0.607

1/ L = Lime at 0 and 8 t/ha;

P = Phosphorus at 0, 45, 90, and 180 kg/ha.

would be extracted. This may explain why there was no differences in the amount of SiO_2 extracted at different P rates. The conclusion would be that P can only have an effect of the water soluble Si but not much effect on how much can be extracted by 0.5M CaCl_2 pH 1.5, which extracts Si in the contiguous phases and that adsorbed on amorphous material and quartz.

2. The effect of lime and phosphorus on inorganic P fractions:

As expected, increased applications of phosphates resulted in greater amounts of extractable P which is reflected in the four forms of active phosphates, namely adsorbed-P, Al-, Fe-, and Ca-P (NaHCO_3 , NH_4F , NaOH , and H_2SO_4 extractable P respectively) (Tables 28-29) Just as in the first lime experiment, the accumulation of these fractions are more clearly related to soil pH as reported by Chang and Jackson (1957) who found that inorganic phosphate in acid Podzolic soils existed generally as iron phosphate with aluminum phosphate a less abundant form.

In an acid soil where no lime or P have been added, the fractions in order of magnitude are Fe-P > Adsorbed-P > Al-P > Ca-P in both the top and subsoils. Adding lime without P changes the order into Ca-P > adsorbed-P > Al-P > Fe-P. This is in agreement with what has already been reported that the shifting between the phosphate fractions may be attributed to the activities of the ions - Al, Fe, and Ca - whereby at acid pH's Fe-P is predominant and at near neutral pH's, Ca-P predominates, with Al-P as intermediate.

Where only P has been added, the picture changes in that whereas the Fe-P and Al-P increase, Ca-P is very slightly affected, although there is general increase in this fraction. Adding lime reverses the whole process,

Table 28. Fractionation of inorganic phosphate of the soil samples from the lime x phosphorus experiment.

Treatment	Adsorbed-P	Al-P	Fe-P	Ca-P	Σ P
<hr/>					
ug/g					
<u>Top Soil</u>					
L ₀ P ₀	13.6	4.9	19.9	3.5	41.9
L ₀ P ₁	29.0	11.0	27.7	4.1	72.0
L ₀ P ₂	46.6	16.7	32.5	4.5	110.3
L ₀ P ₄	98.2	33.1	45.2	5.6	182.1
L ₈ P ₀	14.4	5.6	4.7	22.2	46.9
L ₈ P ₁	36.6	11.0	6.4	31.6	85.6
L ₈ P ₂	70.6	16.6	6.4	40.6	134.2
L ₈ P ₄	134.2	24.7	8.7	49.8	217.4
<hr/>					
<u>Subsoil</u>					
L ₀ P ₀	6.0	1.6	10.5	1.7	19.8
L ₀ P ₁	25.6	6.8	24.4	2.8	59.5
L ₀ P ₂	56.4	13.5	38.6	4.5	113.0
L ₀ P ₄	107.4	22.2	52.2	5.2	187.0
L ₈ P ₀	8.3	2.6	1.8	12.6	25.3
L ₈ P ₁	38.3	7.8	5.1	29.3	80.5
L ₈ P ₂	67.1	12.4	7.1	42.2	128.8
L ₈ P ₄	152.6	22.0	10.1	57.7	242.4

Table 29. Relationship between applied P and soil-P fractions (Lime x phosphorus).

<u>P-fractions</u>	<u>Correlation coefficients</u>	<u>Regression equation</u>
<u>Top soil - unlimed</u>		
Adsorbed-P	0.997	$Y=11.47 + 0.481X$
Aluminum	0.996	$Y= 4.03 + 0.157X$
Iron-P	0.997	$Y=20.56 + 0.137X$
Calcium-P	0.997	$Y= 3.55 + 0.011X$
$\sum P_I$	0.999	$Y=39.62 + 0.787X$
<u>Top soil - limed</u>		
Adsorbed-P	0.998	$Y=10.54 + 0.678X$
Aluminum-P	0.997	$Y= 6.14 + 0.106X$
Iron-P	0.967	$Y= 4.95 + 0.021X$
Calcium-P	0.982	$Y=25.14 + 0.152X$
$\sum P_I$	0.999	$Y=45.77 + 0.950X$
<u>Subsoil - unlimed</u>		
Adsorbed-P	0.998	$Y= 3.63 + 0.574X$
Aluminum-P	0.996	$Y= 1.95 + 0.115X$
Iron-P	0.981	$Y=13.37 + 0.229X$
Calcium-P	0.951	$Y= 1.95 + 0.020X$
$\sum P_I$	0.997	$Y=20.91 + 0.938X$
<u>Subsoil - limed</u>		
Adsorbed-P	0.995	$Y= 3.20 + 0.805X$
Aluminum-P	0.999	$Y= 2.76 + 0.107X$
Iron-P	0.981	$Y= 2.52 + 0.014X$
Calcium-P	0.982	$Y=16.17 + 0.245X$
$\sum P_I$	0.999	$Y=24.65 + 1.201X$

with the Ca-P and adsorbed-P increasing significantly. One postulation for the decrease in Fe-P was that at high pH the iron phosphates are solubilized, Ca-P precipitates, and Al-P is very little changed.

Adsorbed-P increased tremendously with both the P and lime additions. Hsu (1965) reported that when the surface is nearly saturated, the adsorbed phosphate may be slightly available to plants. It can also be perceived that the availability of the adsorbed phosphate may be very difficult when a small amount of phosphate is retained by a large amount of amorphous aluminum hydroxides or iron oxides. It is important to note here that free or clayey sesquioxides account for the major phosphorus fixation; and the lower the silica/sesquioxide ratio, the higher the fixation (Oke, 1970). Several authors (Cloos et al., 1968; Mughogho, 1975, Saunders, 1965) have related the phosphate adsorption and availability levels to the silication degree of the amorphous compounds: P adsorption decreasing and P availability increasing with increasing silicon content. In this case, crystalline materials do not play an important role in the fixing of P. In Chapter IV for example, it was observed that increasing the Si as determined by Tweneboah et al. (1967) procedure had increased P extracted, so that the active amorphous materials influenced the adsorption.

As reported by some authors (Hsu, 1965; Van Olphen, 1963), it is the surface reactive amorphous aluminum hydroxides and iron oxides, but not the Al^{3+} or Fe^{3+} , are the real factors that govern the concentration of phosphate in solution. The activity of Al^{3+} (or Fe^{3+}) is limited by pH, being negligible above pH 5. It appears reasonable, looking at the data

to view precipitation of aluminum or iron phosphate and adsorption of phosphates or polyphosphates on ferric or aluminum oxides or hydroxides as resulting from the same kind of forces; those involved in forming complex ions or salts (Hsu, 1965). Bache (1964) suggests a representation of precipitation products as: $(Al, Fe) \cdot (H_2PO_4)_n(OH)_{3-2}$. It is important, then, to recognize that the formation of new solid phase is concordant with thermodynamic information on the oxides or hydroxides and phosphates. For example, the equilibrium



has an equilibrium constant at 25°C of ca. $10^{-2.5}$. It is important to perceive that when the bulk or surface phase of iron or aluminum orthophosphate is formed, the pH dependence of phosphate precipitation should tend to conform to the solubility diagrams for $FePO_4$ and $AlPO_4$. For phosphate sorption onto $Al(OH)_3(s)$ or $Fe(OH)_3(s)$ there is generally an increase of uptake as the pH is decreased (increasing positive charge on oxide-hydroxide surface).

In general, more P fractions were extracted from the limed than the unlimed soils. This may be due to the fact that liming to increase pH solubilizes some strengite and variscite (Stumm & Morgan, 1975). Liming may prevent the formation of very difficultly soluble forms, thus rendering other P fractions more available. It could also be that since Si adsorption increases with increasing pH, P adsorption sites would be saturated by Si.

The Effect of Lime and Phosphorus on Yield

Two weeks after the first planting, treatments where no P was applied started showing P deficiency symptoms. Leaves were purpling and growth was stunted. In some cases, leaves were necrotic. Deficiency symptoms were more severe in subsoil treatments. Zinc deficiency symptoms appeared in the subsoil treatments where highest P and lime were applied. The first symptoms were streaking in the interveinal areas. On the whole, there was substantial difference in the heights of the maize seedlings (Appendix Table 31).

The second planting did not show as much response to lime and P as in the first planting. This may be due to the fact that as the P and lime were not applied in the second planting, there had been some reaction so that other nutrients, such as trace elements, for example Zn, were not rendered available. In fact, Zn deficiency symptoms were very severe in the second planting, and this was observed in both soil treatments at the highest P and lime treatments. In the early stages, Zn deficiency symptoms appeared as interveinal streaks, and with time there was bleaching of the young leaves in the whorl and the maize seedlings were stunted. The data in Tables 30-31 and Appendix Figure 6 indicate that there was a good response in yield of the maize, and the response was greatest at the lowest P rate (45 kg P/ha) for the unlimed soils. Subsequent P applications increased, but very little, the yield. In the limed soils, there was a good response throughout, which may indicate that P is needed when high lime rates are applied. This supports the

Table 30. Analysis of variance of dry matter weight (g/pot) of maize grown in the lime x phosphorus greenhouse experiment. TOP SOIL - FIRST HARVEST.

LIME		0 t/ha				8 t/ha			
P		0	45	90	180	0	45	90	180
I		4.3	11.2	9.5	11.5	2.6	6.3	8.5	9.8
II		3.9	9.4	12.8	12.9	2.3	6.3	9.2	12.6
III		3.5	8.6	11.4	14.1	3.6	8.9	9.0	9.7
IV		3.5	10.9	11.0	12.5	2.4	7.3	11.9	10.9
TOTAL		15.2	40.1	44.7	51.1	10.6	28.8	38.6	43.0
GRAND TOTAL									272.1

ANOVA

Source	df	SS	MS	F
Treatment	7	368.5775		
Factor A	3	337.1188	112.373	80.21
Factor B	1	28.3131	28.313	20.21
Inter AB	3	3.1456	1.048	0.75
Error	24	33.6225	1.401	
TOTAL	31	402.2000		

SUBSOIL

LIME		0 t/ha				8 t/ha			
P		0	45	90	180	0	45	90	180
I		1.8	7.6	8.5	8.9	1.3	2.3	4.9	6.3
II		1.8	4.4	7.5	9.5	1.0	4.7	5.5	7.8
III		1.8	8.0	8.8	8.0	1.8	2.8	8.4	5.8
IV		2.1	8.8	8.5	8.0	1.2	3.8	5.5	8.2
TOTAL		7.5	28.8	33.3	34.4	5.3	13.6	24.3	28.1

ANOVA

Source	df	SS	MS	F
Treatment	7	232.457		
Factor A	3	187.886	62.629	51.69
Factor B	1	33.415	33.415	27.58
Inter AB	3	11.156	3.719	3.07
Error	24	29.078	1.212	
TOTAL	31	261.535		

Table 31. Analysis of variance of dry matter weight (g/pot) of maize grown in the lime x phosphorus greenhouse experiment. TOP SOIL - SECOND HARVEST.

LIME		0 t/ha				8 t/ha			
P		0	45	90	180	0	45	90	180
I		4.8	7.4	9.7	10.0	6.5	10.1	9.0	8.3
II		4.2	6.8	8.0	9.2	7.7	10.0	7.5	9.2
III		4.4	6.7	8.6	8.4	6.4	8.7	9.2	8.4
IV		3.5	6.6	8.6	9.5	6.7	7.7	10.6	9.6
TOTAL		16.9	27.4	34.9	37.1	27.3	36.5	36.4	35.5
GRAND TOTAL									252.0

ANOVA

Source	df	SS	MS	F
Treatment	7	88.885		
Factor A	3	64.412	21.471	34.60
Factor B	1	11.761	11.761	18.95
Inter AB	3	12.711	4.237	6.83
Error	24	14.895	0.621	
TOTAL	31	105.780		

SUBSOIL

LIME		0 t/ha				8 t/ha			
P		0	45	90	180	0	45	90	180
I		2.1	3.5	6.0	8.6	2.1	3.0	2.6	6.9
II		1.7	4.6	6.1	6.1	2.0	2.3	3.6	7.7
III		1.6	3.2	5.2	8.5	1.3	3.6	3.7	2.5
IV		2.6	3.5	5.1	8.1	1.6	2.3	2.0	6.3
TOTAL		8.0	14.8	22.4	31.3	7.0	11.2	11.9	23.4
GRAND TOTAL									130.0

ANOVA

Source	df	SS	MS	F
Treatment	7	128.900		
Factor A	3	105.572	35.191	32.19
Factor B	1	16.531	16.531	15.12
Inter AB	3	6.796	2.265	2.07
Error	24	26.235	1.093	
TOTAL	31	155.135		

suggestion that lime may cause P to precipitate as Ca-P when limed to near neutral. In their experiments with rye and millet, Amarasiri and Olsen (1973) found that yields and percent P of rye were significantly increased by P without lime, but that the response to added P was greater in presence of lime. This is in agreement with the present work. In case of millet, there was response to P only when soils were limed to pH 5 or 6, and beyond this, the yield was depressed.

In the second planting, the unlimed soils showed a great response from residual P up to the highest P rate, with the subsoil showing the greatest response, whereas the limed top soil only showed a good response up to 45 kg P/ha. The failure for the yield to increase tremendously in the second planting gives an indication that some factors other than P or lime are controlling the growth. As already mentioned, Zn in the present case is suspected. High lime rates coupled with high P rates accentuates the situation. From the table, it can be observed that the main treatments had a significant effect on yield, with P having a positive effect, and lime a negative effect.

Nutrient uptake:

Although liming depressed P uptake, thus P deficiency was suspected, liming did not increase P uptake even when P was applied, an indication that liming was not beneficial in the present study, (Tables 32 & 33). This may be due to the fact that the present experiment was done at a very high lime rate (8 t/ha lime) whereby many factors may be affected by the treatment. Fox et al. (1964), for example, found that liming an

Table 32. Nutrient uptake by maize as affected by lime and phosphorus application in the top soil. FIRST HARVEST.

Treat	Yield	P	Ca	Mg	K	Zn
	g/pot	mg/pot				
L ₀ P ₀	3.80	6.5	28.5	19.0	256	0.342
L ₀ P ₁	10.02	23.1	52.1	40.1	461	0.421
L ₀ P ₂	11.18	29.1	50.3	40.2	626	0.615
L ₀ P ₄	12.78	62.6	57.5	38.3	783	0.664
L ₈ P ₀	2.72	4.6	37.6	10.9	184	0.142
L ₈ P ₁	7.30	16.8	73.0	30.7	431	0.256
L ₈ P ₂	9.65	27.0	91.7	34.7	592	0.396
L ₈ P ₄	19.75	41.9	102.1	35.5	769	0.430

Nutrient uptake by maize as affected by lime and phosphorus application in the subsoil. FIRST HARVEST.

Treat	Yield	P	Ca	Mg	K	Zn
	g/pot	mg/pot				
L ₀ P ₀	1.88	2.1	13.5	6.2	134	0.137
L ₀ P ₁	7.20	20.2	32.4	15.8	418	0.288
L ₀ P ₂	8.32	32.5	26.6	13.3	474	0.358
L ₀ P ₄	8.60	58.5	27.5	13.7	592	0.404
L ₈ P ₀	1.32	1.6	27.6	4.8	51	0.057
L ₈ P ₁	3.40	4.8	50.0	9.2	180	0.143
L ₈ P ₂	6.08	15.2	65.6	14.6	380	0.219
L ₈ P ₄	7.02	33.7	71.7	12.6	473	0.288

L = Lime at 0 and 8 t/ha;

P = Phosphorus at 0, 45, 90, and 180 kg/ha.

Table 33. Nutrient uptake by maize as affected by lime and phosphorus applications in the top soil. SECOND HARVEST.

Treat	Yield	P	Ca	Mg	K	Zn
	g/pot	mg/pot				
L ₀ P ₀	4.22	6.8	31.7	23.2	220	0.253
L ₀ P ₁	6.85	13.7	44.5	37.7	219	0.253
L ₀ P ₂	8.72	19.2	56.7	43.6	218	0.340
L ₀ P ₄	9.28	21.3	53.8	35.2	408	0.325
L ₈ P ₀	6.82	15.7	81.9	37.5	300	0.280
L ₈ P ₁	9.12	26.5	88.5	56.6	266	0.411
L ₈ P ₂	9.10	26.4	81.0	51.0	278	0.309
L ₈ P ₄	8.88	27.5	75.4	48.4	390	0.275

Nutrient uptake by maize as affected by lime and phosphorus applications in the subsoil. SECOND HARVEST.

Treat	Yield	P	Ca	Mg	K	Zn
	g/pot	mg/pot				
L ₀ P ₀	2.00	2.2	13.0	7.2	112	0.114
L ₀ P ₁	3.70	5.2	23.3	11.1	181	0.166
L ₀ P ₂	5.60	9.5	26.9	12.9	260	0.291
L ₀ P ₄	7.82	20.3	25.0	12.5	415	0.336
L ₈ P ₀	1.75	1.6	28.0	5.8	88	0.058
L ₈ P ₁	2.80	3.6	43.4	9.0	140	0.109
L ₈ P ₂	2.98	5.6	46.1	10.7	152	0.170
L ₈ P ₄	5.85	11.7	55.6	11.7	304	0.246

aluminous ferruginous latosol to pH 6.1 increased uptake of fertilizer P, but liming up to pH 7 markedly decreased P uptake by sorghum and DESMODIUM INTORTUM, although they did not get this marked decrease at pH 7 with a humic ferruginous latosol. A possible explanation for these results could be the strength of P adsorption by the soils. Rates of lime which neutralize exchangeable Al result in more efficient uptake of P from Ultisols and Oxisols. However, lime rates which raise the pH to 7 will probably cause a marked decrease in P availability particularly where P is adsorbed very strongly (Fox et al., 1964; Woodruff & Kamprath, 1965; Reeve & Sumner, 1970). Brans (1971) also found similar results as in the present study in that there was no response to lime, but that there was response only to P. Thus, it can be explained that the failure for the maize to respond may be from the fact that there was adequate Ca in the soils, and also that at higher pH's other factors may be limiting, and one of the main suggestions is that Zn might be limiting in the present case.

Calcium in the limed soil increased significantly in both the top soil and subsoil treatments. It is important to note that increased P application reduced percent Ca in plants, although uptake was increasing with P application. In the unlimed soils, though, the increase in Ca uptake was only significant at the lowest P-rate, and subsequent P application did not improve on Ca uptake in both soils.

In the second planting, there was no substantial difference in Ca uptake in the limed top soil when P was increased. There was an increase in Ca, uptake in the unlimed top soil and the limed subsoil. There was a very low level of Ca uptake in unlimed subsoil.

Lime application did not seem to have much effect on the Mg uptake in the first planting. In the second planting, lime application seemed to have increased Mg uptake in the top soil, and had no influence in Mg uptake in the subsoil. P application increased Mg uptake in the top soil much more than in the subsoil. Whereas there was no significant effect of lime on K uptake, P application increased K uptake in both soils and in both plantings.

There was greater uptake of Zn in the unlimed soil, and that lime application depressed Zn uptake, which may indicate that lime decreased Zn availability either through physiological processes in the plant system or that Zn is rendered unavailable by formation of difficulty soluble complexes under pH values near neutral. The present work is in agreement with what has been reported in that lime application may decrease Zn uptake (Wear, 1956; Meuer et al., 1971). Induced deficiencies in this matter are related more to the ratio of the nutrients in the plants rather than concentration in the plants per se.

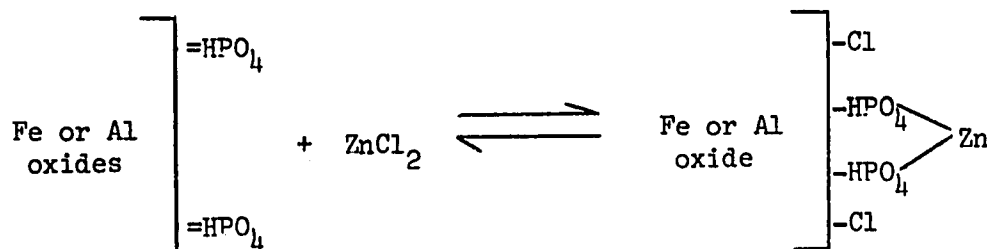
VI. THE EFFECT OF LIME, PHOSPHORUS, AND ZINC APPLICATION ON MAIZE YIELD

Introduction

The relationship between lime and Zn, or P and Zn is widely recognized. In most cases it has been observed that where incipient deficiencies are known to exist, overliming such soils may cause Zn deficiencies (Younge & Plucknett, 1963; Fox & Plucknett, 1964; Meuer et al., 1971). A number of studies have also shown that plant uptake of Zn is decreased by liming. The Zn content of sorghum was sharply decreased by addition of one ton of lime per hectare to a Norfolk soil with an initial pH of 5.6 (Wear, 1956). In greenhouse work, Meuer et al. (1971) found that liming up to pH 5.5 did not affect Zn uptake, but to pH 6.5 caused Zn deficiency symptoms in soils with less than 1.5 ppm Zn while liming to pH 7.4 gave Zn deficiency symptoms in all soils, but that rates of applied P did not affect Zn uptake. Their work was with three Oxisols and one Alfisol ranging from 1.3 ppm Zn (Alfisol) to 2.2 ppm Zn (Oxisol). Keefer and Singh (1968) in their pot experiments found a Zn and P response in that without Zn fertilization response to P application was found up to 50 mg P/g soil on one soil and 200 mg P/g on the other. When Zn was applied, the efficiency of all levels of P increased on both soils.

Stanton and Burger (1968) mentioned that Zn adsorption occurs when P has been added in presence of hydrous Fe or Al oxides, the mechanism being

as follows:



This would mean that in the absence of hydrous Fe oxide the addition of phosphate has little effect on Zn adsorption. They verified their studies with intact seedlings, thus supported the evidence that phosphated hydrous Fe oxides fix Zn against absorption by roots. The absence of phosphate, then would seem to reduce the availability of sorbed Zn as the crystallinity of the sesquioxides decreases. Tiller (1968), working on the interaction of some heavy metals and silicic acid in the clays found that the amount of Zn adsorbed increased with the amount of silicic acid adsorbed. This means that adsorption of silicic acid provides additional sites only, which may be the same mechanism as that of P.

Watanabe et al. (1965), working with corn and pinto beans observed that induced nutrient deficiencies with addition of one nutrient without addition of another were related more to the ratio of nutrient levels in plant than their concentration per se. In their studies, they used the ratio P/Zn as an important index for predicting Zn deficiency. This is in agreement with the work of Boawn and Brown (1968) who concluded that normal metabolism is dependent upon a physiological balance between P and Zn. The possible biological mechanism by which imbalance disrupts normal metabolic processes may involve translocation (Boawn & Brown, 1968). Sharma et al.

(1968) found that Zn concentration was reduced in the tons due to P application, but that the Zn concentration was much less influenced by applied P. With P, the concentration was reduced by applying one ppm Zn, although the effect was primarily with higher rates of P. Thus it can be concluded that P does not fix Zn, but that the mechanism of translocation is involved.

There has been little information on Zn status or availability in tropical Africa, and may be this is attributed to the fact that low yielding varieties under traditional systems of agriculture are carried on (Osiname et al 1973). There have been Zn deficiencies reported, for example, on tree crops in Kenya where Zn deficiency was found on coffee, and Malawi where Zn deficiency symptoms on tung trees were induced by use of excess $\text{Ca}_3(\text{PO}_4)_2$ and that ZnSO_4 applied in spring and autumn was found effective.

In Ghana, Zn deficiency symptoms have been found in cacao (Theobroma cacao L.) by Ahenkorah (1968). Greenland and Hayfron (1951) reported Zn deficiencies in cacao, and they attributed this to Zn deficiencies induced by high pH. When pH was below 7.5, no Zn deficiencies were observed, but when it was above they observed some deficiencies. Cunningham (1964) also found similar results where pH was high due to the fact that brush was burned on the spot, thus causing the pH to rise. Not much work on maize has been reported in relation to Zn deficiency.

The present study was undertaken to check if P and/or Zn application would alleviate the poor growth that results from overliming the top- and sub-soils.

Materials and Methods

Top soil and subsoil were used in the present experiment. Lime, phosphorus and zinc were applied as follows:

Lime - 0 and 8 tons/ha (L_0 and L_8) as $\text{Ca}(\text{OH})_2$.

Phosphorus - 0, 45 and 180 kg/ha (P_0 , P_1 , and P_4),
as KH_2PO_4 .

Zinc - 0, 1, and 4 ppm (Zn_0 , Zn_1 , and Zn_4)
as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$

Basal treatments of N and K were as in the previous greenhouse experiments. The duration of the experiment was 28 days.

Soil Analysis.

Soil samples from each treatment were composited for analysis.

P was determined by the Olsen and Watanabe (1957) single extraction procedure.

Zinc was extracted by 0.1N HCl at 1:10 soil:solution ratio and Zn in solution was determined by the atomic absorption spectrophotometry (Trierweiler & Lindsay, 1969)

Maize Growth.

Maize growth was determined by weighing and measuring height of maize at time of harvest.

Tissue analysis was done as before.

Results and Discussion

1. Effect of lime, phosphorus, and zinc on soil P and Zn

In general, the top soil had more P and Zn than the subsoil.

Results in Table 3⁴ show that increased P application either increased acid-extractable Zn from soils or showed no change, and this may indicate that P and Zn did not chemically combine. Similar results were found by Keefer and Singh (1968). From these results, one may postulate that increased P does not irreversibly fix Zn into unavailable form.

On the whole, Zn application increased acid-extractable Zn in both soils but that it did not increase NaHCO_3 -extractable P, except in the limed top soil at the highest rate of fertilizer P (180 kg/ha). This also shows that there was not much fixation of P by Zn, and if there was any, the P was extractable by the dilute acid and that it was available for plant use.

There was as much Zn extracted from the unlimed as from the limed soils, which gives an indication that some or most of the Zn was available for plant use, if acid-extractable Zn is a good measure for plant available Zn. It can be concluded from the present results that since P and Zn were not found to precipitate in the soil, and that lime did not irreversibly fix Zn, increased P and lime in the soil only changed the physiological ability of the plant to absorb Zn where there were detrimental effects of high lime rates or P applications.

Kamprath (1971) pointed out that liming soils with low native supply

Table 34. The effect of lime, phosphorus, and zinc application on NaHCO_3 -extractable P and 0.1N HCl extractable Zn(ug/g).

Treatment			Top Soil		Subsoil	
L	P	Zn	P	Zn	P	Zn
0	0	0	5.08	1.0	2.12	0.4
0	0	1	6.40	2.2	1.97	7.4
0	0	4	6.14	6.8	2.00	16.4
0	45	0	15.38	1.0	15.23	0.4
0	45	1	17.69	2.4	13.85	1.2
0	45	4	18.31	6.2	19.23	5.8
0	180	0	47.44	1.0	62.82	0.8
0	180	1	57.44	2.2	58.97	1.4
0	180	4	64.10	5.4	58.97	2.8
8	0	0	8.92	1.0	3.14	0.6
8	0	1	9.69	2.0	3.85	1.6
8	0	4	9.11	7.4	3.45	7.6
8	45	0	20.00	1.0	37.85	0.8
8	45	1	21.54	5.9	39.23	2.4
8	45	4	22.31	17.6	34.15	6.4
8	180	0	56.92	0.1	111.54	2.4
8	180	1	61.28	2.2	137.18	10.2
8	180	4	62.56	5.2	158.46	12.2

P = single extraction.

of Zn to pH 7 will reduce the availability of Zn and very likely induce Zn deficiencies, particularly under intensive cropping. From the present results, one would be led to conclude differently since both the top soil and subsoil showed very little depression in extractability of Zn by the dilute acid.

According to Stanton and Burger (1968), the adsorption of Zn by P occurs in the presence of hydrous iron or aluminum oxides, which means that in the absence of hydrous Fe or Al oxides the addition of P has little effect on Zn adsorption. Similar results were found by Tiller (1968) who found a correlation between Zn adsorption and the adsorption of silicic acid. It could also be that 0.1N HCl extracts some of the Zn that is adsorbed by amorphous materials. The same can be said of the P which had been adsorbed by the amorphous materials in that it can be extracted by the bicarbonate extraction.

2. The effect of lime, phosphorus, and zinc application on maize yield

On the whole, there was a great response to P application in the top soil at all levels of P (Tables 35 and 36 and Appendix Tables 32 and 33). The yield increase was highly significant at $P = 0.01$ in all cases. This is a clear indication that these soils respond to P application. Lime, on the other hand, has a depressing effect on the top growth even on soils that received P, which means that the nutrient imbalance is attributed to some nutrient other than P.

There was no significant response to Zn application when no lime was applied, and this may be due to the fact that there was adequate Zn avail-

Table 35. The effect of Lime x Phosphorus x Zinc on maize growth of the top soil, in g/pot.

LIME	ZINC	PHOSPHORUS			TOTAL
		P ₀	P ₁	P ₄	
L ₀	Zn ₀	9.8	31.7	45.9	87.4
	Zn ₁	10.3	36.0	35.7	82.0
	Zn ₄	11.6	36.4	41.4	89.4
	TOTAL	31.7	104.1	123.0	258.8
L ₈	Zn ₀	8.6	20.6	25.3	54.5
	Zn ₁	7.3	23.8	30.0	61.1
	Zn ₄	10.1	26.9	36.7	73.7
	TOTAL	26.0	71.3	92.0	189.3
Total for LIME	Zn ₀	18.4	52.3	71.2	141.9
	Zn ₁	17.6	59.8	65.7	143.1
	Zn ₄	21.7	63.3	78.1	163.1
	TOTAL	57.7	175.4	215.0	448.1

ANOVA

Source	df	SS	MS	F
Replicates	1	16.7	16.7	7.60
Treatments				
Phosphorus (P)	2	1113.8	556.9	253.7
Lime (L)	1	134.2	134.2	61.1
Zinc (Zn)	2	23.6	11.8	5.4
L x P	2	40.2	20.1	9.2
P x Zn	4	15.7	3.9	1.8
L x Zn	2	13.0	6.5	3.0
L x P x Zn	4	26.1	6.5	3.0
ERROR	17	37.3	2.2	
TOTAL	35	1420.6		

Table 36. The effect of Lime x Phosphorus x Zinc on maize growth of the subsoil, in g/pot.

LIME	ZINC	PHOSPHORUS			TOTAL
		P ₀	P ₁	P ₄	
L ₀	Zn ₀	2.6	19.5	29.8	51.9
	Zn ₁	2.9	20.2	22.2	45.3
	Zn ₄	2.6	24.2	29.8	56.6
	TOTAL	8.1	63.9	81.8	153.8
L ₈	Zn ₀	2.7	4.3	3.4	10.4
	Zn ₁	2.5	8.7	22.1	33.3
	Zn ₄	2.6	14.1	24.8	41.5
	TOTAL	7.8	27.1	50.3	85.2
Total for LIME	Zn ₀	5.3	23.8	33.2	62.3
	Zn ₁	5.4	28.9	44.3	78.6
	Zn ₄	5.2	38.3	54.6	98.1
	TOTAL	15.9	91.0	132.1	239.0

ANOVA

Source	df	SS	MS	F
Replicates	1	11.1	11.1	5.6
Phosphorus (P)	2	578.6	289.3	144.8
Lime (L)	1	130.7	130.7	65.4
Zinc (Zn)	2	53.5	26.8	13.4
L x P	2	64.8	32.4	16.2
P x Zn	4	30.8	7.7	3.8
L x Zn	2	57.5	14.4	7.2
ERROR	17	34.0	2.0	
TOTAL	35	1004.9		

able for plant use. On the other hand, Zn application was beneficial when the top soil was limed. The response to Zn when lime was applied supports the postulation that liming soils with low supply of Zn to pH 7 will reduce the availability of Zn and likely induce Zn deficiency, since Zn is less available at high pH's (Peech, 1941; Shurman, 1965).

In the subsoil treatments, there was a great response to P application, and also that lime had a depressing effect on yield. The depressing effect of lime was greatest when no Zn was applied both at zero level and the highest P rate (180 kg P/ha). When no lime was applied, there was no significant difference to Zn application, which may support the suggested reports that when native soil Zn level is below 1.5 ppm, applied lime depresses yield, and once above that critical level, there is not much difference (Meuer et al. 1971). At the highest lime rates, Zn has a great effect on the top growth yield, and it seems as if there was little effect of P on Zn. However, there is a response to Zn as well as of P at high lime rates. Olsen (1972) pointed out that for the limed soils, applied Zn increased yield only when P was applied.

At each level of P application in both unlimed and limed top soil there was no effect on P uptake with increased Zn application. For the subsoil, Zn application lowered P uptake at the highest P rate in the unlimed treatments, whereas in the limed subsoil, there was an increase in P uptake with Zn application where P was applied. This is mostly due the fact that when the soil is limed, P and Zn may be tied up, and thus rendering these nutrients unavailable. In general, P uptake is greater in the unlimed than limed soils. (Tables 37 & 38).

Table 37. The effect of lime, phosphorus, and zinc on nutrient uptake by maize on the top soil treatments, mg/pot.

Treat*	Yield	P	Ca	Mg	K	Zn	N
	g/pot						
L ₀ P ₀ Zn ₀	4.90	9.8	31	20	274	0.49	201
L ₀ P ₀ Zn ₁	5.15	8.8	32	22	273	0.52	200
L ₀ P ₀ Zn ₄	5.80	10.4	32	22	325	0.75	226
L ₀ P ₁ Zn ₀	15.85	38.0	76	60	580	0.71	507
L ₀ P ₁ Zn ₁	18.00	41.4	86	77	630	1.24	558
L ₀ P ₁ Zn ₄	18.20	41.9	91	78	637	1.46	557
L ₀ P ₄ Zn ₀	22.95	124.9	101	76	1262	1.33	695
L ₀ P ₄ Zn ₁	17.85	82.1	70	57	981	1.02	531
L ₀ P ₄ Zn ₄	20.70	83.6	77	56	962	2.07	548
L ₈ P ₀ Zn ₀	4.30	11.2	42	16	254	0.56	176
L ₈ P ₀ Zn ₁	3.65	8.8	39	14	232	0.27	144
L ₈ P ₀ Zn ₄	5.05	10.1	50	19	268	0.71	189
L ₈ P ₁ Zn ₀	10.30	30.9	79	39	505	0.28	369
L ₈ P ₁ Zn ₁	11.90	29.8	104	52	575	0.42	426
L ₈ P ₁ Zn ₄	13.45	30.9	110	51	557	0.70	436
L ₈ P ₄ Zn ₀	12.65	55.7	80	46	806	0.44	421
L ₈ P ₄ Zn ₁	15.00	54.0	96	45	840	0.42	486
L ₈ P ₄ Zn ₄	18.35	55.0	110	55	918	0.62	539

* L = Lime at 0 and 8 t/ha;

P = Phosphorus at 0, 45, and 180 kg/ha;

Zn = Zinc at 0, 1, and 4 parts per million.

Table 38. The effect of lime, phosphorus, and zinc on nutrient uptake by maize on subsoil treatments, mg/pot.

Treat*	Yield	P	Ca	Mg	K	Zn	N
	g/pot						
L ₀ P ₀ Zn ₀	1.30	1.3	8	5	77	0.07	53
L ₀ P ₀ Zn ₁	1.45	1.4	8	5	78	0.17	58
L ₀ P ₀ Zn ₄	1.30	1.4	7	4	76	0.29	51
L ₀ P ₁ Zn ₀	9.75	25.4	28	18	566	0.37	340
L ₀ P ₁ Zn ₁	10.10	23.2	35	21	545	0.68	324
L ₀ P ₁ Zn ₄	12.10	23.0	36	21	554	1.09	328
L ₀ P ₄ Zn ₀	14.90	89.4	37	21	983	0.77	434
L ₀ P ₄ Zn ₁	11.10	62.2	28	16	694	0.58	343
L ₀ P ₄ Zn ₄	14.90	50.7	37	19	834	0.83	366
L ₈ P ₀ Zn ₀	1.35	1.4	23	4	45	0.05	65
L ₈ P ₀ Zn ₁	1.25	1.2	16	3	35	0.04	60
L ₈ P ₀ Zn ₄	1.30	1.2	20	4	30	0.08	63
L ₈ P ₁ Zn ₀	2.15	5.2	31	6	91	0.05	101
L ₈ P ₁ Zn ₁	4.35	9.1	49	10	196	0.18	170
L ₈ P ₁ Zn ₄	7.05	12.0	75	16	298	0.34	221
L ₈ P ₄ Zn ₀	1.70	8.2	19	4	85	0.05	92
L ₈ P ₄ Zn ₁	11.05	40.9	98	23	724	0.41	397
L ₈ P ₄ Zn ₄	12.40	37.2	103	21	748	0.54	336

* L = Lime at 0 and 8 t/ha;

P = Phosphorus at 0, 45, and 180 kg/ha;

Zn = Zinc at 0, 1, and 4 parts per million.

There was an increase in Ca uptake with increased Zn application. On the other hand, increased P fertilization did not have much effect on Ca uptake to distinguish between the two high rates (45 and 180 kg P/ha) in the top soil. A greater Ca uptake was observed at the highest P rate and Zn rates in the subsoil treatments.

In general, there was an increase in Mg and K uptake when both Zn and P were applied in both soils. On the other hand, lime application reduced the uptake of Mg and K.

Whereas Zn uptake was depressed by lime application, the effect was greater in the subsoil than the top soil. The depressing effect of lime on Zn uptake is greatest where native soil Zn content was low. In both soil treatments, increased P and Zn application increased Zn uptake, with the highest uptake observed in the top soil. The fact that Zn deficiency symptoms were more frequent in the limed soils would suggest that the formation of insoluble reaction products at high pH would limit diffusion of Zn to the roots. The results in the present work are in agreement with those of Melton et al. (1973). Zn deficiency symptoms induced by high P rates appeared to have been caused by the precipitation of Zn by P more in soils with low levels of Zn or by a high soil pH. Many workers have reported that increased P application increased Zn content of the roots and decreased Zn content of the topgrowth. This was attributed to failure of the complexed Zn in being translocated to the topgrowth when P fertilization was increased (Keefer & Singh, 1968; Dwivedi et al., 1975). Dwivedi et al. (1975) suggested the use of P/Zn ratio as an index to

help in understanding the P-Zn interaction and its consequent effect on crop production. The lower P/Zn ratio did seem to be associated with P deficiencies and the highest P/Zn ratio with Zn deficiencies. Similar results were observed by Watanabe et al. (1965) and Boawn and Brown (1968). Where incipient deficiencies are known to exist, such as the subsoil in the present case, overliming may cause Zn deficiencies (Younge & Plucknett, 1963; Fox & Plucknett, 1964; Meuer et al., 1971). Wear (1956), for example, observed a sharp decrease in Zn content of sorghum when a Norfolk with an initial pH of 5.6 was limed one ton of lime per hectare.

Conclusions

From the results, lime application limited yield response of maize in the absence of other nutrients such as P and Zn. The failure to get a greater response to applied P and Zn when lime was applied may indicate that other nutrients were limiting, and the subsoil seemed to be more affected. This may be due to the fact that the subsoil was less buffered. Lime application increased Ca uptake, and that the effect was greatest when both P and Zn were applied. Thus, under intensive cropping on these soils, lime application would have to be limited to low rates of application, for example 1/2 - 1 ton per hectare. On the other hand, if higher lime rates are to be applied, a basal application of Zn would be necessary since these soils show incipient deficiencies, more especially the subsoil.

VII.

GENERAL CONCLUSIONS

In the present study, field and greenhouse experiments were conducted on an Ultisol in the forest region of Ghana to study the effect of lime application on maize growth and some soil properties.

Lime application did not significantly increase maize grain yield in either the major or minor growing season. Since there was a modest response to first increment of lime in the field experiment, one would be led to conclude that the lime required for optimum plant growth for the Kumasi soil was low.

Results from the short term greenhouse experiments show that the effect of excess lime application was to depress maize growth and that the effect was accentuated when the soil had a lower buffering capacity, such as the subsoil in the present study.

Response of maize growth to applied P was significant, and the effect was greatest at the lowest P rate. This may indicate that these soils have a low P requirement, and this was reflected in their low P adsorption maxima.

Overliming depressed the maize growth, and this was attributed to P and Zn deficiencies. There were significant responses to both applied P and Zn although the application of these elements did not alleviate the depressing effect of overliming these soils.

Aluminum in these soils does not seem to be much of a problem, if acid infertility is associated with high Al saturation. From the results obtained so far, it can be assumed that liming should be restricted to those situations where Ca is limiting as a nutrient.

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Appendix Table 1. The effect of lime on exchangeable Ca in the top soil, in me/100 g soil.

Treat/Rep <u>1/</u>	I	II	III	IV	V	VI	MEAN
0	4.99	3.62	5.24	2.87	4.99	6.74	4.742
1/2	4.62	6.45	7.36	4.86	6.74	4.49	5.753
1	8.73	5.24	6.99	4.74	3.68	7.61	6.165
2	5.74	7.48	5.74	7.36	5.73	5.11	6.195
4	18.11	9.48	4.99	8.23	7.24	8.98	9.505

ANOVA

Source	df	SS	MS	F
Treatment	4	772.84	193.20	3.37
Replicates	5	270.75	54.15	0.94
Error	20	1144.50		
Total	29	2188.08		

Appendix Table 2. The effect of lime on subsoil exchangeable Ca, in me/100 g soil.

Treat/Rep <u>1/</u>	I	II	III	IV	V	VI	MEAN
0	2.37	0.87	2.12	1.00	0.87	2.24	1.578
1/2	1.25	1.62	3.99	1.00	2.24	1.75	1.975
1	1.37	2.00	1.87	1.50	1.00	2.12	1.643
2	1.25	1.50	2.62	1.50	1.00	1.37	1.540
4	1.87	1.37	1.62	3.99	1.12	1.62	1.932

ANOVA

Source	df	SS	MS	F
Treatment	4	1.003	0.2508	0.41
Replicates	5	4.175	0.8349	1.36
Error	20	12.203	0.6101	
Total	29	17.381		

1/ Lime = Tons/ha.

Appendix Table 3. The effect of lime on BaCl_2 -TEA exchange acidity (top soil), in me/100 g soil.

Treat/Rep 1/	I	II	III	IV	V	VI	MEAN
0	5	9	7	7	10	5	7.2
1/2	8	6	7	5	7	7	6.7
1	5	6	5	5	9	7	6.2
2	8	5	6	6	7	6	6.3
4	1	5	6	3	7	2	4.0

ANOVA

Source	df	SS	MS	F
Treatment	4	35.53	8.883	3.92
Replicates	5	27.07	5.413	2.39
Error	20	45.27	2.263	
Total	29	107.87		

Appendix Table 4. The effect of lime on the subsoil BaCl_2 -TEA acidity, in me/100 g soil (sub soil).

Treat/Rep 1/	I	II	III	IV	V	VI	MEAN
0	6	5	8	8	5	5	6.2
1/2	6	5	3	4	5	6	4.8
1	4	4	7	5	5	5	5.0
2	7	5	4	6	5	7	5.7
4	5	6	6	3	5	6	5.2

ANOVA

Source	df	SS	MS	F
Treatment	4	7.1333	1.7833	1.02
Replicates	5	2.9667	0.5933	0.34
Error	20	34.8667	1.7433	
Total	29	44.9667		

1/ Lime = Tons/ha.

Appendix Table 5. The effect of lime on top soil cation exchange capacity, in me/100 g soil.

Treat/Rep 1/	I	II	III	IV	V	VI	MEAN
0	11.3	12.7	15.2	10.2	14.0	13.8	12.87
1/2	13.1	13.9	12.8	10.6	15.9	14.0	13.38
1	13.9	11.1	13.0	12.8	11.7	16.4	13.15
2	14.4	13.3	12.2	13.7	12.1	12.2	12.98
4	14.2	13.9	9.1	10.9	12.8	10.8	11.95

ANOVA

Source	df	SS	MS	F
Treatment	4	7.207	1.8017	0.57
Replicates	5	12.315	2.4629	0.78
Error	20	62.365	3.1183	
Total	29	81.887		

Appendix Table 6. The effect of lime on top soil sum of the cations (Σ cations), in me/100 g soil.

Treat/Rep 1/	I	II	III	IV	V	VI	MEAN
0	11.0	13.8	13.8	10.7	16.4	13.4	13.19
1/2	13.4	14.0	15.9	11.1	15.4	12.8	13.77
1	15.3	12.4	13.6	11.0	13.4	16.3	13.65
2	14.7	13.8	12.9	14.7	13.7	11.9	13.61
4	23.0	16.0	12.1	12.3	15.3	11.6	15.06

ANOVA

Source	df	SS	MS	F
Treatment	4	11.923	2.981	0.51
Replicates	5	38.494	7.699	1.32
Error	20	115.926	5.796	
Total	29	166.344		

1/ Lime = Tons/ha.

Appendix Table 7. The effect of lime on subsoil cation exchange capacity, in me/100 g soil.

Treat/Rep 1/	I	II	III	IV	V	VI	MEAN
0	8.0	6.3	10.8	8.4	6.4	7.0	7.82
1/2	8.1	7.2	11.9	6.1	7.9	6.7	7.98
1	7.8	8.3	8.2	8.1	5.2	7.0	7.43
2	8.0	7.7	7.8	7.3	5.8	6.7	7.22
4	7.3	6.5	7.4	9.3	6.0	7.5	6.26

ANOVA

Source	df	SS	MS	F
Treatment	4	2.582	0.6455	0.47
Replicates	5	25.342	5.0683	3.75
Error	20	27.010	1.3505	
Total	29	54.934		

Appendix Table 8. The effect of lime on subsoil sum of cations, in me/100 g soil.

Treat/Rep 1/	I	II	III	IV	V	VI	MEAN
0	9.1	6.3	11.0	9.4	6.2	8.0	8.32
1/2	7.6	7.1	12.0	5.8	7.9	8.4	8.17
1	6.2	6.9	9.4	7.2	6.3	7.8	7.30
2	8.7	7.1	7.3	7.9	6.3	8.8	7.71
4	7.9	7.8	8.2	7.8	6.5	8.0	7.70

ANOVA

Source	df	SS	MS	F
Treatment	4	4.0155	1.0039	0.75
Replicates	5	25.9700	5.1940	3.90
Error	20	26.5713	1.3286	
Total	29	56.5568		

1/ Lime = Tons/ha.

Appendix Table 9. The effect of lime on NaHCO_3 -extractable P in the top soil (ppm).

Treat/Rep <u>1</u> /	I	II	III	IV	V	VI	MEAN
0	4.95	6.85	5.51	3.92	7.79	6.01	5.838
1/2	6.85	6.07	4.67	5.14	5.76	7.32	5.968
1	6.01	9.19	6.07	5.14	7.38	7.69	6.913
2	4.52	4.95	5.14	7.79	7.48	6.04	5.987
4	7.66	7.69	4.98	6.23	6.85	5.76	6.528

ANOVA

Source	df	SS	MS	F
Treatment	4	5.0135	1.2534	0.91
Replicates	5	13.0753	2.6151	1.91
Error	20	27.3074	1.3654	
Total	29	45.3962		

Appendix Table 10. The effect of lime on subsoil NaHCO_3 - extractable P (ppm).

Treat/Rep <u>1</u> /	I	II	III	IV	V	VI	MEAN
0	1.70	1.24	1.04	0.84	1.50	1.16	1.247
1/2	1.93	1.42	2.47	0.97	1.11	1.70	1.600
1	1.36	1.16	1.86	1.19	1.36	1.16	1.348
2	1.14	1.31	1.08	2.13	1.82	1.70	1.530
4	0.77	1.28	1.55	2.40	1.13	0.88	1.335

ANOVA

Source	df	SS	MS	F
Treatment	4	0.5195	0.1299	0.55
Replicates	5	0.3567	0.07135	0.30
Error	20	4.6596	0.23298	
Total	29	5.5359		

1/ Lime = Tons/ha.

Appendix Table 11. The effect of lime on soil Zn (ppm)-Top soil

Treat/Rep <u>1</u> /	I	II	III	IV	V	VI	MEAN
0	2.4	1.6	1.8	1.4	2.0	2.0	1.87
1/2	1.6	3.0	1.8	2.0	2.0	1.4	1.97
1	3.6	2.0	2.0	2.2	1.4	1.2	2.07
2	2.2	2.2	1.6	1.8	2.0	0.6	1.73
4	3.6	2.6	1.4	1.4	1.4	0.4	1.80

ANOVA

Source	df	SS	MS	F
Treatment	4	0.4213	0.2975	0.84
Replicates	5	7.1587	1.4317	4.26
Error	20	6.7147	0.3357	
Total	29	14.2947		

Appendix Table 12. The effect of lime on subsoil Zn (ppm).

Treat/Rep <u>1</u> /	I	II	III	IV	V	VI	MEAN
0	0.6	0.2	0.8	0.1	0.8	1.2	0.62
1/2	0.1	0.8	0.8	0.2	0.6	0.8	0.55
1	0.2	0.8	0.2	0.2	0.8	1.0	0.53
2	0.1	0.8	0.2	0.8	0.2	0.6	0.45
4	0.4	0.8	0.2	1.2	0.8	0.8	0.70

ANOVA

Source	df	SS	MS	F
Treatment	4	0.2113	0.05283	0.50
Replicates	5	1.0950	0.21900	2.03
Error	20	2.0967	0.10483	
Total	29	3.4030		

1/ Lime = Tons/ha.

Appendix Table 13. The effect of lime on per cent organic matter of the top soil.

Treat/Rep <u>1/</u>	I	II	III	IV	V	VI	MEAN
0	3.2	3.1	4.1	2.3	5.0	4.2	3.65
1/2	3.3	4.0	4.0	3.0	4.2	4.0	3.75
1	4.7	3.4	3.8	2.7	3.4	4.4	3.73
2	3.6	3.5	3.7	4.1	3.5	3.3	3.62
4	4.1	4.4	3.5	3.1	3.9	3.0	3.67

ANOVA

Source	df	SS	MS	F
Treatment	4	0.076667	0.019167	0.04
Replicates	5	2.757667	0.551533	1.43
Error	20	7.667333	0.383367	
Total	29	10.501667		

Appendix Table 14. Effect of lime on subsoil per cent organic content.

Treat/Rep <u>1/</u>	I	II	III	IV	V	VI	MEAN
0	1.8	1.1	1.6	1.2	0.8	1.3	1.30
1/2	1.3	1.4	1.9	0.9	1.3	1.3	1.35
1	1.0	1.4	1.6	1.1	1.2	1.5	1.30
2	1.3	1.2	1.4	1.1	0.9	1.0	1.15
4	1.4	1.4	1.1	2.1	1.5	1.1	1.24

ANOVA

Source	df	SS	MS	F
Treatment	4	0.25533	0.063833	0.68
Replicates	5	0.40667	0.081333	0.86
Error	20	1.87667	0.093833	
Total	29	2.53867		

1/ Lime = Tons/ha.

Appendix Table 15. The effect of lime on per cent P in plant tissues.

Treat/Rep <u>1/</u>	I	II	III	IV	V	VI	MEAN
0	0.39	0.34	0.44	0.38	0.32	0.38	0.373
1/2	0.39	0.35	0.38	0.42	0.33	0.36	0.372
1	0.39	0.34	0.34	0.35	0.35	0.33	0.348
2	0.38	0.36	0.34	0.34	0.32	0.33	0.345
4	0.33	0.26	0.31	0.32	0.31	0.34	0.312

ANOVA

Source	df	SS	MS	F
Treatment	4	0.01506	0.003767	5.45
Replicates	5	0.00972	0.001944	2.81
Error	20	0.01381	0.000691	
Total	20	0.39600		

Appendix Table 16. The effect of lime on per cent N in plant tissues

Treat/Rep <u>1/</u>	I	II	III	IV	V	VI	MEAN
0	3.69	3.76	4.41	4.41	4.05	3.50	3.406
1/2	4.11	3.90	4.00	3.80	3.84	4.16	3.968
1	3.64	4.05	3.76	3.90	3.68	3.89	3.820
2	4.29	3.80	3.76	3.80	3.89	3.68	3.870
4	3.69	3.85	4.05	3.50	3.89	4.11	3.848

ANOVA

Source	df	SS	MS	F
Treatment	4	1.138	0.2845	0.55
Replicates	5	2.128	0.4257	0.82
Error	20	10.292	0.5146	
Total	29	13.558		

1/ Lime = Tons/ha.

Appendix Table 17. The effect of lime on per cent Mg in plant tissue

Treat/Rep	1/	I	II	III	IV	V	VI	MEAN
0		0.26	0.34	0.37	0.29	0.35	0.37	0.330
1/2		0.37	0.30	0.35	0.31	0.35	0.31	0.332
1		0.31	0.37	0.28	0.28	0.30	0.38	0.320
2		0.33	0.40	0.31	0.30	0.37	0.38	0.348
4		0.34	0.29	0.28	0.27	0.31	0.37	0.310

ANOVA

Source	df	SS	MS	F
Treatment	4	0.00491	0.001228	0.98
Replicates	5	0.01472	0.002944	2.35
Error	20	0.02595	0.001253	
Total	20	0.44680		

Appendix Table 18. The effect of lime on per cent Ca in plant tissue.

Treat/Rep	1/	I	II	III	IV	V	VI	MEAN
0		0.56	0.65	0.67	0.51	0.67	0.72	0.630
1/2		0.77	0.60	0.76	0.60	0.70	0.63	0.677
1		0.67	0.72	0.53	0.51	0.75	0.82	0.667
2		0.67	0.82	0.75	0.67	0.77	0.60	0.713
4		0.65	0.70	0.53	0.58	0.72	0.75	0.655

ANOVA

Source	df	SS	MS	F
Treatment	4	0.02247	0.00517	0.83
Replicates	5	0.07182	0.01436	2.12
Error	20	0.13493	0.00675	
Total	29	0.22917		

1/ Lime = Tons/ha

Appendix Table 19. The effect of lime on per cent K in plant tissue.

Treat/Rep 1/	I	II	III	IV	V	VI	MEAN
0	7.46	6.30	7.98	7.00	6.50	7.30	7.09
1/2	8.34	7.46	8.50	7.00	7.00	6.80	7.16
1	7.46	8.43	7.10	7.80	6.00	6.50	7.22
2	7.98	6.30	7.60	6.30	6.65	7.30	7.02
4	7.30	6.30	7.10	7.00	7.00	7.00	6.95

ANOVA

Source	df	SS	MS	F
Treatment	4	1.1902	0.2975	0.84
Replicates	5	4.6001	0.9200	2.62
Error	20	7.0131	0.3506	
Total	29	12.8033		

Appendix Table 20. The effect of lime on Zn (ppm) in plant tissue

Treat/Rep 1/	I	II	III	VI	V	VI	MEAN
0	29	23	25	26	26	24	25.5
1/2	27	24	19	28	21	36	25.8
1	25	24	27	24	20	20	23.3
2	26	22	21	25	25	22	23.5
4	25	24	26	22	24	28	24.8

ANOVA

Source	df	SS	MS	F
Treatment	4	31.200	7.800	0.65
Replicates	5	48.800	9.760	0.82
Error	20	237.200	11.860	
Total	29	317.200		

1/ Lime = Tons/ha.

Appendix Table 21. The effect of lime on the maize growth for the top soil, in g/pot. FIRST HARVEST

Treat/Rep	I	II	III	IV	MEAN
0	13.6	14.6	14.7	14.9	14.45
1	10.4	14.1	15.7	13.6	13.45
2	12.1	12.5	14.0	12.4	12.75
4	10.1	11.1	11.0	11.7	10.90
8	7.7	6.4	9.0	9.3	8.10

ANOVA

Source	df	SS	MS	F
Treatment	4	99.652	24.913	24.33
Replicates	3	12.314	4.104	4.00
Error	12	12.284	1.024	
Total	19	124.250		

Appendix Table 22. The effect of lime on the maize growth for the sub-soil treatments, g/pot. FIRST HARVEST

Treat/Rep	I	II	III	IV	MEAN
0	8.4	9.2	7.0	9.3	8.48
1	6.2	7.1	6.7	8.6	7.15
2	6.5	6.8	5.6	6.8	6.42
4	3.7	4.1	4.1	5.5	4.35
8	2.9	1.5	1.9	3.3	2.40

ANOVA

Source	df	SS	MS	F
Treatment	4	92.093	23.023	62.18
Replicates	3	7.112	2.371	6.40
Error	12	4.443	0.370	
Total	19	103.648		

Appendix Table 23. The effect of lime on maize growth for the Top/
sub soil treatments, in g/pot. FIRST HARVEST

Treat/Rep	I	II	III	IV	MEAN
0	12.3	11.7	12.0	13.2	12.30
1	12.1	10.8	12.7	13.8	12.35
2	11.5	7.9	12.7	12.1	11.05
4	10.4	8.6	10.6	12.8	10.60
8	10.1	12.0	12.0	9.8	10.98

ANOVA

Source	df	SS	MS	F
Treatment	4	10.562	2.6405	1.61
Replicates	3	13.430	4.4765	2.74
Error	12	19.598	1.6332	
Total	19	43.590		

Appendix Table 24. The effect of lime on the maize growth for the top soil treatments, in g/pot. SECOND HARVEST.

Treat/Rep.	I	II	III	IV	MEAN
0	14.9	16.3	15.2	13.2	14.90
1	16.0	14.1	15.6	13.8	14.88
2	16.3	15.4	17.3	14.4	14.85
4	16.2	17.4	10.2	16.2	15.10
8	17.6	16.3	21.3	19.3	18.62

ANOVA

Source	df	SS	MS	F
Treatment	4	40.457	10.114	2.05
Replicates	3	1.818	0.606	0.12
Error	12	59.067	4.922	
Total	19	101.342		

Appendix Table 25. The effect of lime on the maize growth for the sub-soil treatments, in g/pot. SECOND HARVEST.

Treat/Rep	I	II	III	IV	MEAN
0	11.6	11.2	10.7	12.0	11.38
1	13.2	9.8	10.1	12.2	11.32
2	7.2	12.3	11.9	12.4	10.95
4	9.9	7.6	8.4	9.9	8.95
8	4.5	3.9	4.6	6.5	4.88

ANOVA

Source	df	SS	MS	F
Treatment	4	122.567	30.618	13.48
Replicates	3	8.398	2.799	1.23
Error	12	27.265	2.272	
Total	19	158.230		

Appendix Table 26. The effect of lime on the maize growth for the Top/
sub soil treatments. SECOND HARVEST.

Treat/Rep	I	II	III	IV	MEAN
0	14.7	14.0	13.8	14.5	14.25
1	15.9	13.8	12.9	15.6	14.55
2	14.8	14.4	13.2	17.0	14.85
4	17.5	12.3	13.6	15.8	14.80
8	15.4	13.5	13.6	15.5	14.50

ANOVA

Source	df	SS	MS	F
Treatment	4	0.948	0.237	0.27
Replicates	3	23.410	7.803	8.93
Error	12	10.480	0.873	
Total	19	34.838		

Appendix Table 27. The effect of lime on the maize growth for the top soil treatments, in g/pot. THIRD HARVEST.

Treat/Rep	I	II	III	IV	MEAN
0	13.8	15.7	15.2	14.2	14.72
1	17.0	17.3	18.3	14.9	16.88
2	14.5	15.1	17.5	13.3	15.10
4	13.7	12.6	13.5	12.5	13.08
8	15.5	13.9	14.9	13.4	14.42

ANOVA

Source	df	SS	MS	F
Treatment	4	30.038	7.510	9.78
Replicates	3	12.420	4.140	5.39
Error	12	9.210	0.768	
Total	19	51.668		

Appendix Table 28. The effect of lime on maize growth for the subsoil treatments, in g/pot. THIRD HARVEST

Treat/Rep	I	II	III	IV	MEAN
0	11.7	14.1	11.9	13.2	12.72
1	13.9	13.2	13.5	13.6	13.55
2	10.8	15.0	14.0	11.8	12.90
4	11.9	10.2	7.5	10.0	9.90
8	4.9	3.6	6.3	7.5	5.58

ANOVA

Source	df	SS	MS	F
Treatment	4	174.817	43.704	16.33
Replicates	3	1.682	0.561	0.20
Error	12	32.103	2.675	
Total	19	208.602		

Appendix Table 29. The effect of lime on maize growth for the Top/
sub soil treatments, in g/pot. THIRD HARVEST

Treat/Rep	I	II	III	IV	MEAN
0	17.8	13.8	14.3	17.9	15.95
1	13.0	15.3	14.7	14.1	14.28
2	17.5	15.0	14.1	17.7	16.08
4	16.1	12.9	15.0	15.2	14.80
8	12.4	12.1	12.9	13.2	12.65

ANOVA

Source	df	SS	SS	F
Treatment	4	31.335	7.834	4.28
Replicates	3	11.482	3.827	2.09
Error	12	21.933	1.828	
Total	19	64.750		

Appendix Table 30. The effect of lime on the maize heights from the greenhouse lime experiment
(Average from 4 reps.), cm.

Treat		Top Soil			Subsoil			Top/sub-soil		
t/ha	Week	P1 ₁	P1 ₂	P1 ₃	P1 ₁	P1 ₂	P1 ₃	P1 ₁	P1 ₂	P1 ₃
0	2	45	60	56	40	56	54	49	60	58
0	3	67	83	86	60	81	81	66	84	88
0	4	91	110	114	87	101	108	91	108	115
1	2	46	60	56	41	58	57	46	58	57
1	3	64	85	86	54	81	83	65	82	85
1	4	88	110	111	71	101	106	89	108	109
2	2	44	61	56	41	56	55	44	59	58
2	3	64	86	87	52	73	80	63	85	86
2	4	89	113	111	65	90	101	87	108	110
4	2	41	58	52	38	54	52	43	60	58
4	3	59	85	81	45	67	70	60	85	88
4	4	88	114	109	60	82	89	88	111	112
8	2	37	62	55	32	47	44	43	59	56
8	3	48	88	85	38	55	48	59	82	85
8	4	87	121	111	45	62	55	94	107	108

Appendix Table 31. The effect of lime and phosphorus application on maize height (cm).

Treat/ t/ha	Rep	First planting					Second planting				
		I	II	III	IV	Ave	I	II	III	IV	Ave
<u>TOP SOIL</u>											
L ₀ P ₀		69	72	76	78	74	68	72	70	70	70
L ₀ P ₁		92	102	104	111	102	75	97	82	88	86
L ₀ P ₂		98	114	103	110	106	92	92	88	92	91
L ₀ P ₄		100	113	106	115	108	91	92	78	93	88
L ₈ P ₀		66	56	70	72	66	95	94	90	92	93
L ₈ P ₁		89	87	96	98	92	101	97	97	99	98
L ₈ P ₂		96	88	90	106	95	97	88	92	96	93
L ₈ P ₄		87	92	89	91	90	80	83	85	86	84
<u>SUBSOIL</u>											
L ₀ P ₀		53	52	54	54	53	54	43	47	54	50
L ₀ P ₁		97	84	99	104	96	68	72	67	67	68
L ₀ P ₂		91	94	96	06	94	70	81	74	82	77
L ₀ P ₄		94	99	101	104	100	82	78	95	92	87
L ₈ P ₀		48	40	51	36	44	48	46	44	45	46
L ₈ P ₁		58	69	61	68	64	62	50	60	46	54
L ₈ P ₂		69	84	88	74	79	50	62	60	52	56
L ₈ P ₄		84	84	64	82	78	78	85	46	74	71

Appendix Table 32. The effect of lime, phosphorus, and zinc application on yield of maize, g/pot.

Treatment <u>1/</u>			Top soil			Subsoil		
			I	II	Mean	I	II	Mean
0	0	0	5.50	4.30	4.90	1.30	1.30	1.30
0	0	1	5.30	5.00	5.15	1.30	1.60	1.45
0	0	4	6.00	5.60	5.80	1.20	1.40	1.30
0	45	0	14.90	16.80	15.85	9.50	10.00	9.75
0	45	1	17.10	18.90	18.00	10.00	10.20	10.10
0	45	4	18.20	18.20	18.20	12.80	11.40	12.10
0	180	0	25.80	20.10	22.95	16.40	13.40	14.90
0	180	1	18.40	17.30	17.95	11.60	10.60	11.10
0	180	4	22.40	19.00	20.70	14.20	15.60	14.90
8	0	0	5.00	3.60	4.30	1.50	1.20	1.35
8	0	1	3.90	3.40	3.65	1.40	1.10	1.25
8	0	4	4.40	5.70	5.05	1.30	1.30	1.30
8	45	0	12.20	8.40	10.30	2.00	2.30	2.15
8	45	1	12.30	11.50	11.90	5.80	2.90	4.35
8	45	4	14.40	12.50	13.45	10.00	4.10	7.05
8	180	0	13.30	12.00	12.65	2.20	1.20	1.70
8	180	1	17.10	12.90	15.00	13.70	8.40	11.05
8	180	4	20.10	16.60	18.35	13.30	11.50	12.40

1/ Treatments:

L = tons/ha;

P = kg/ha;

Zn = ppm.

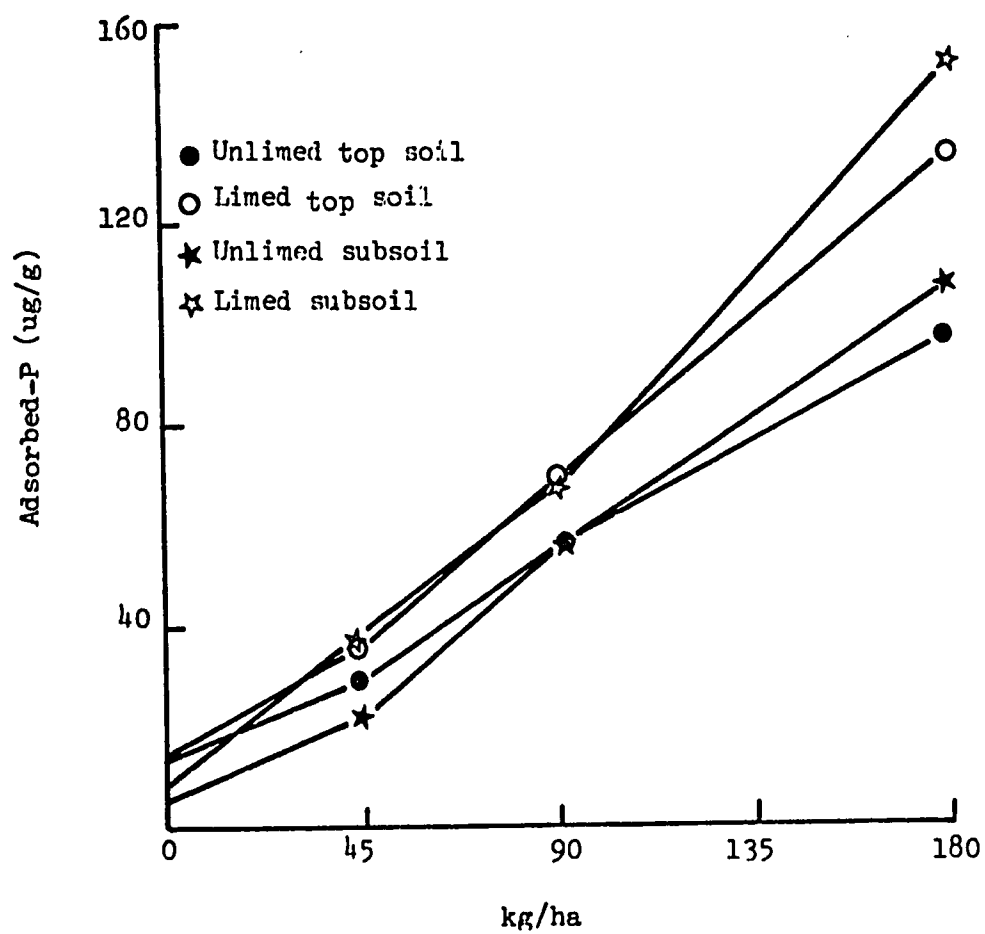
Appendix Table 33. The effect of lime, phosphorus, and zinc on the height of maize (cm) measured at harvest time.

Height of maize (cm) measured at harvest time.							
Treatment	TOP SOIL			SUBSOIL			
Rep	I	II	Ave	I	II	Ave	
L ₀ P ₀ Zn ₀	85	97	91	41	41	41	
L ₀ P ₀ Zn ₁	80	91	86	46	46	46	
L ₀ P ₀ Zn ₄	89	91	90	44	46	45	
L ₀ P ₁ Zn ₀	112	106	109	112	106	109	
L ₀ P ₁ Zn ₁	128	140	134	100	115	108	
L ₀ P ₁ Zn ₄	136	122	129	113	100	106	
L ₀ P ₄ Zn ₀	124	127	126	100	100	100	
L ₀ P ₄ Zn ₁	135	120	128	113	113	113	
L ₀ P ₄ Zn ₄	134	124	129	102	112	107	
L ₈ P ₀ Zn ₀	90	72	81	32	37	34	
L ₈ P ₀ Zn ₁	78	76	77	38	40	39	
L ₈ P ₀ Zn ₄	78	80	79	48	42	45	
L ₈ P ₁ Zn ₀	107	103	105	45	44	44	
L ₈ P ₁ Zn ₁	113	116	114	04	60	82	
L ₈ P ₁ Zn ₄	106	113	110	96	81	88	
L ₈ P ₄ Zn ₀	102	98	100	36	35	36	
L ₈ P ₄ Zn ₁	127	115	121	106	103	104	
L ₈ P ₄ Zn ₄	131	128	130	114	119	116	

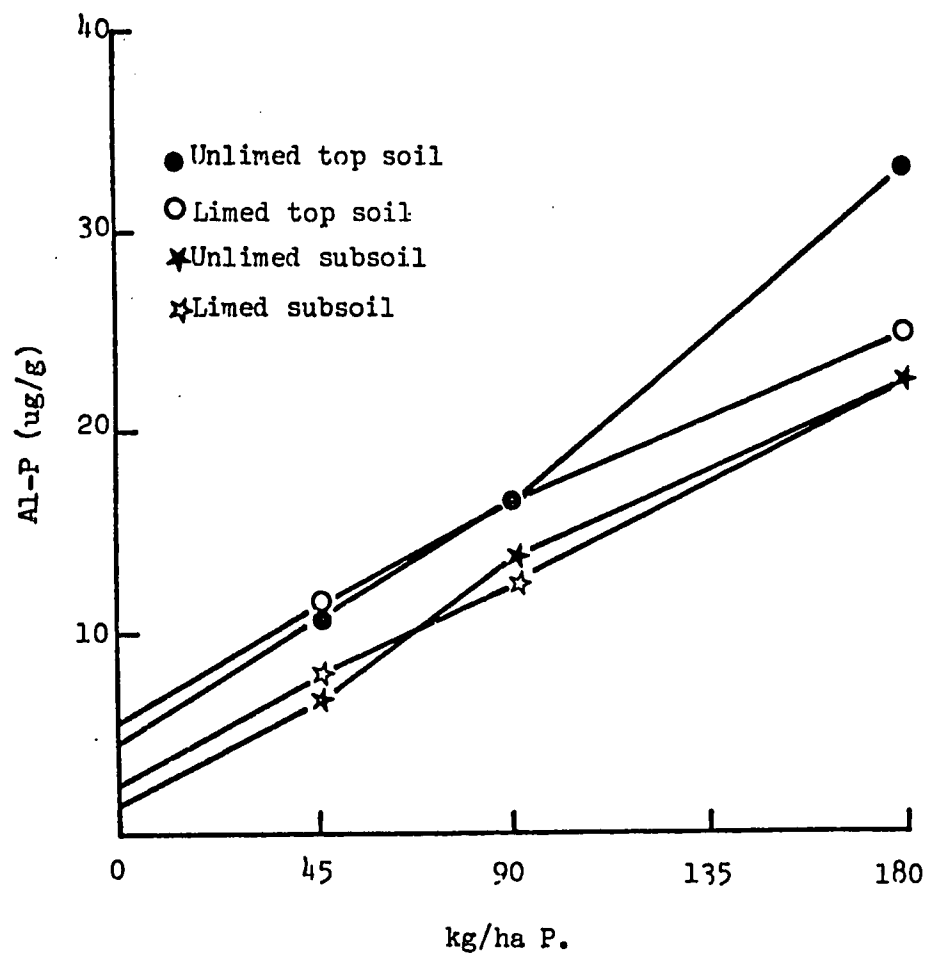
L = 0 and 8 t/ha lime;

P = 0, 45, and 180 kg/ha phosphorus;

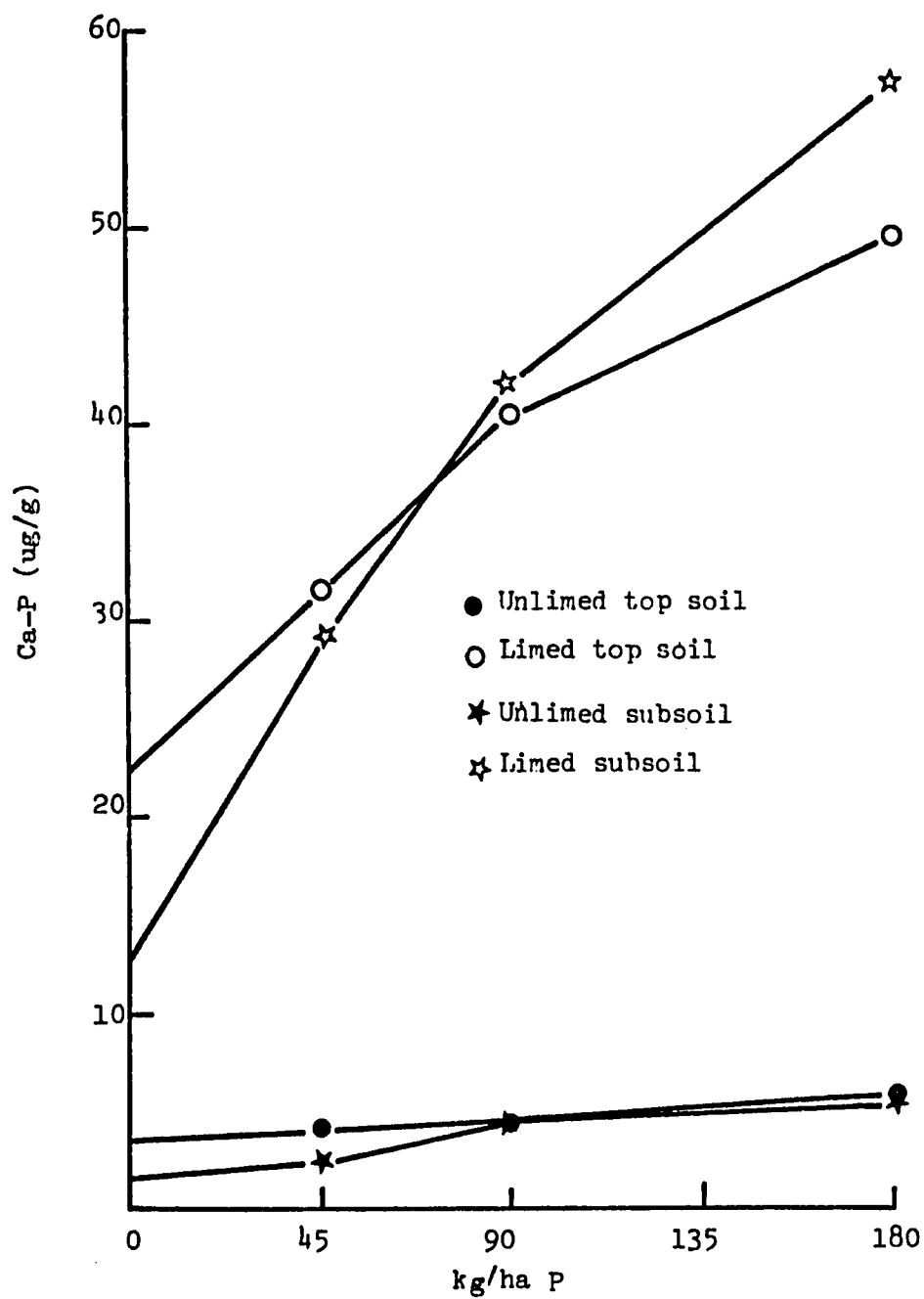
Zn = 0, 1, and 4 parts per million Zinc.



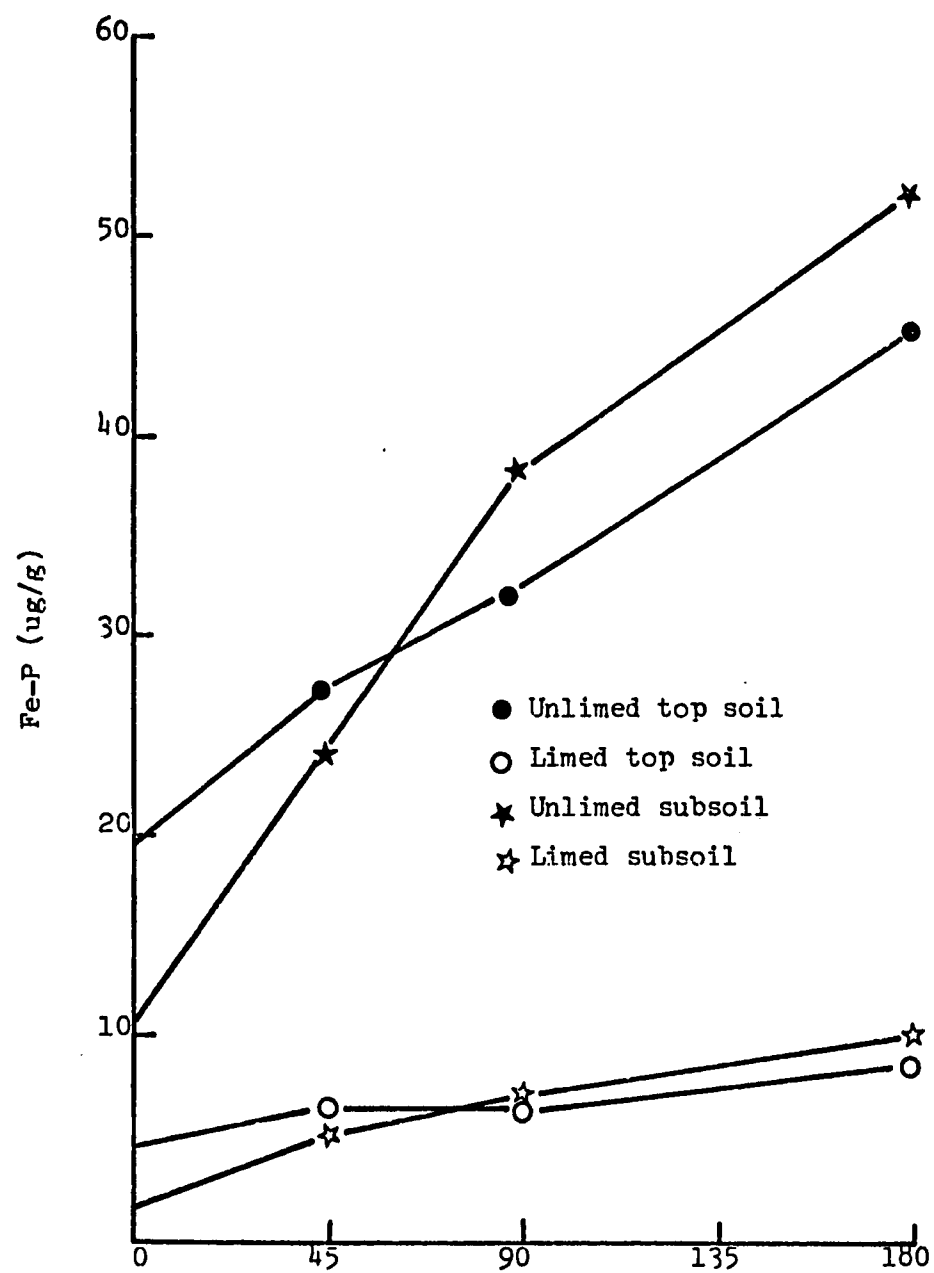
Appendix Figure 1. The effect of lime and phosphorus application on Adsorbed-P.



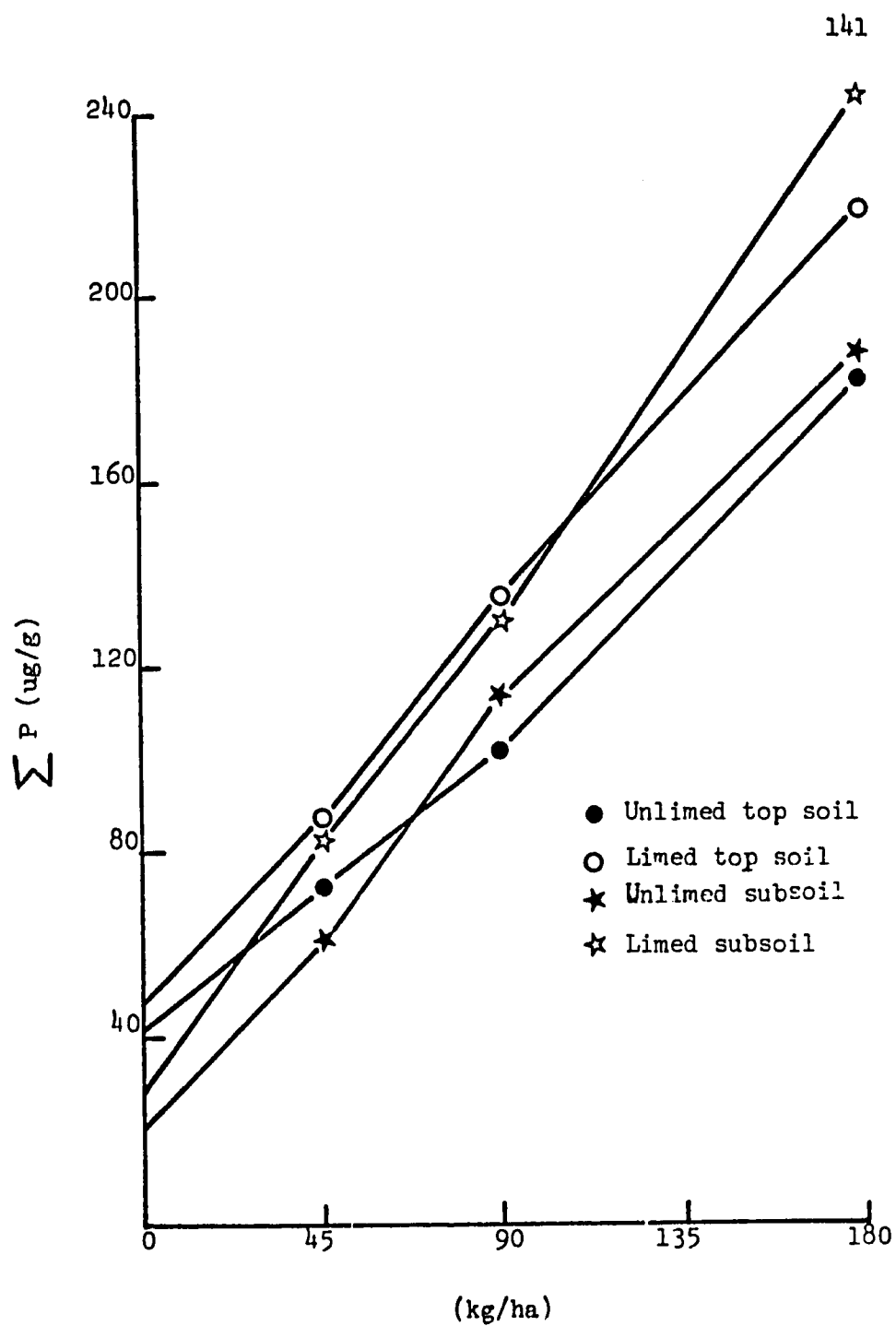
Appendix Figure 2. The effect of lime and phosphorus application on Aluminum-P.



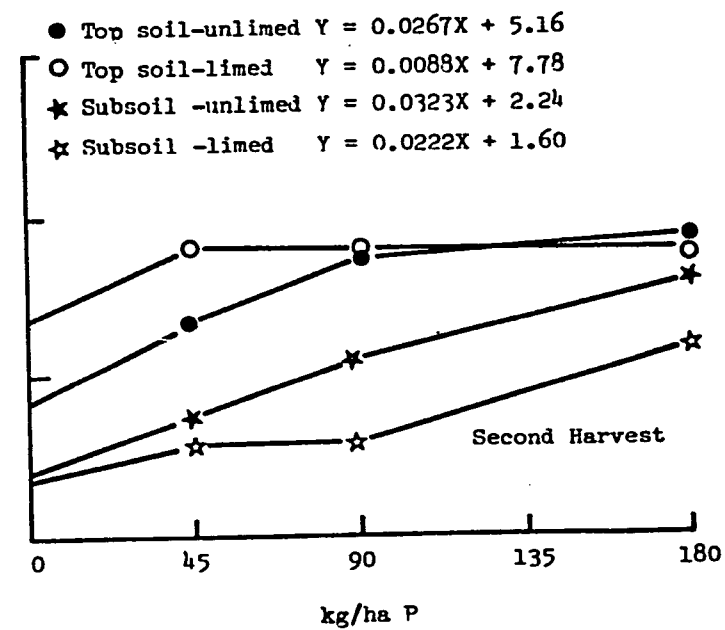
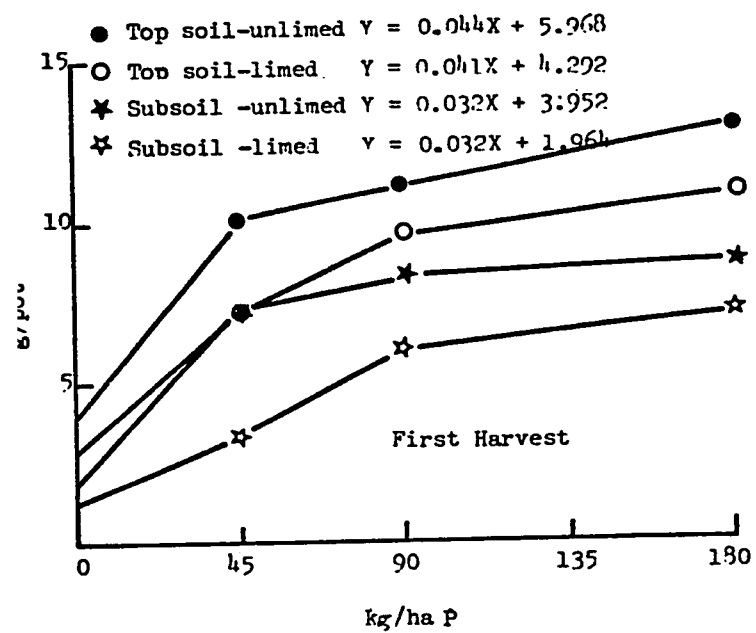
Appendix Figure 3. The effect of lime and phosphorus application on Calcium-P.



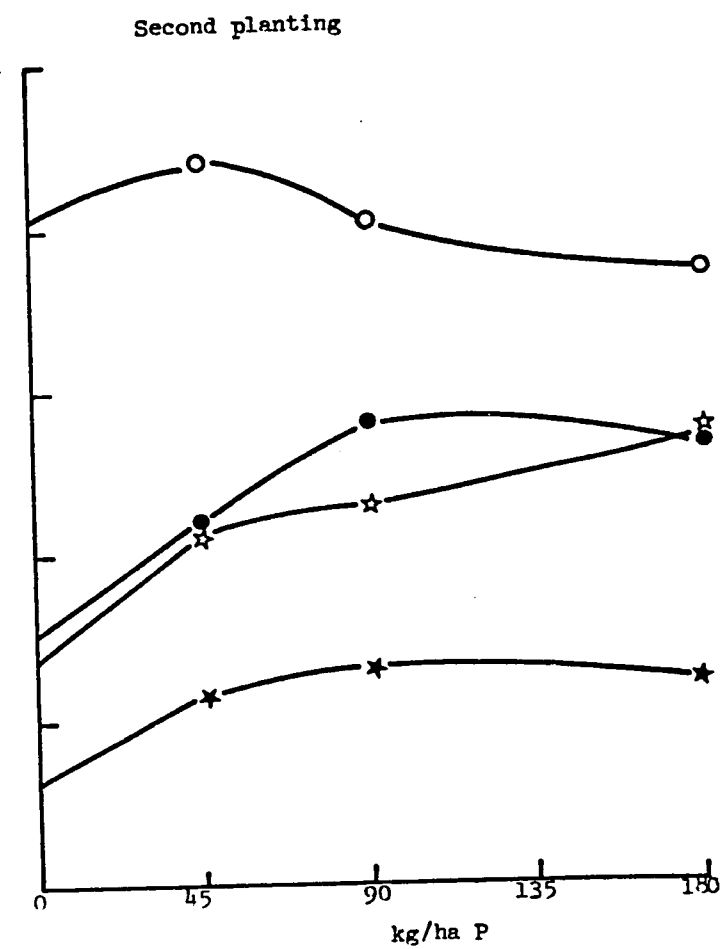
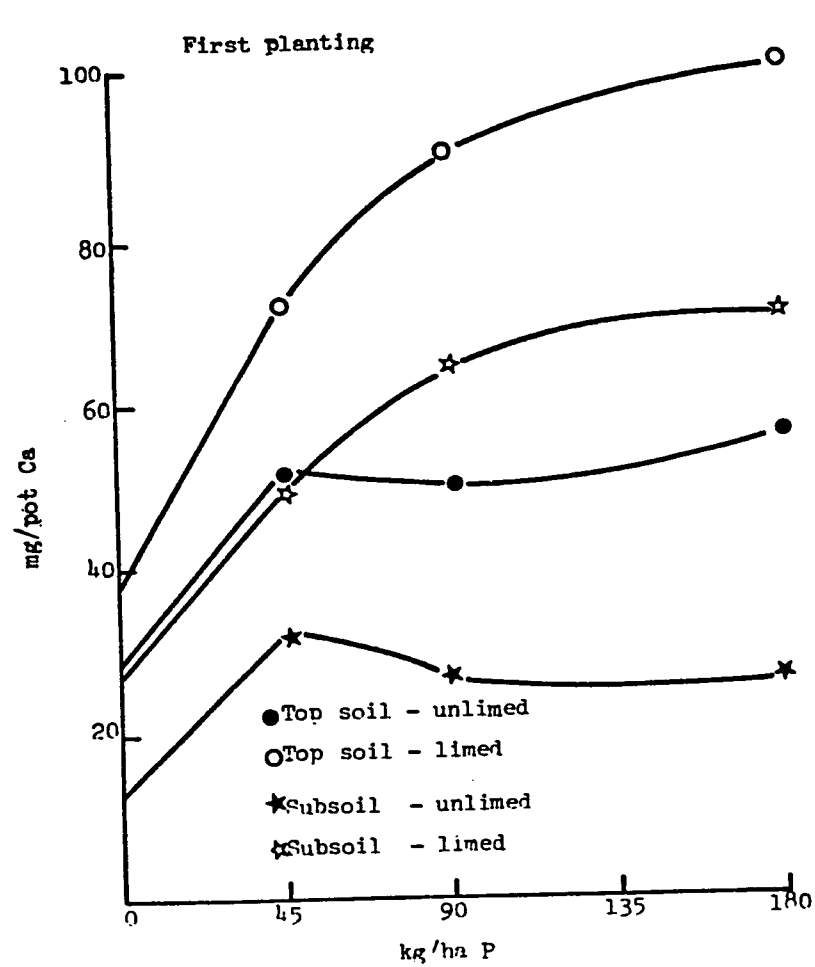
Appendix Figure 4. The effect of lime and phosphorus application on iron-P.



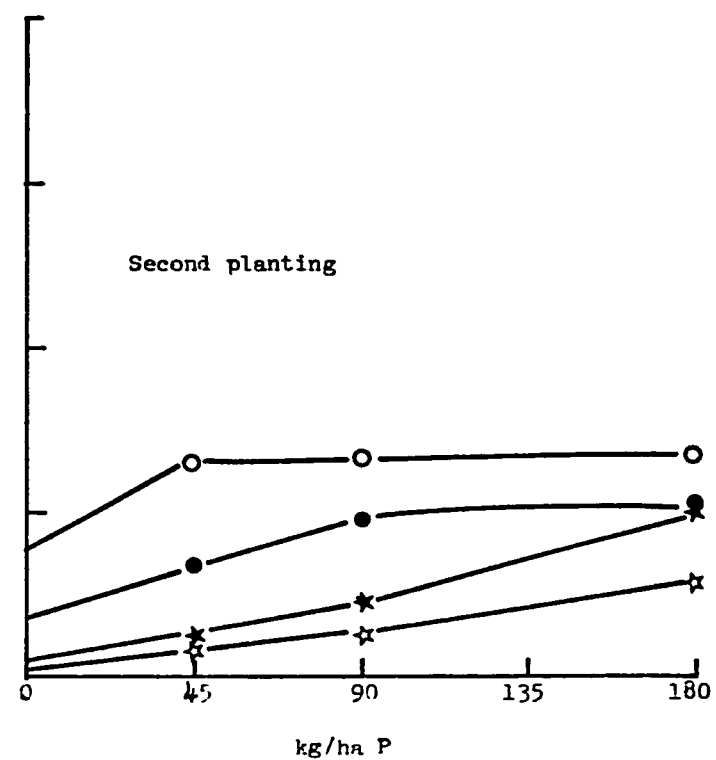
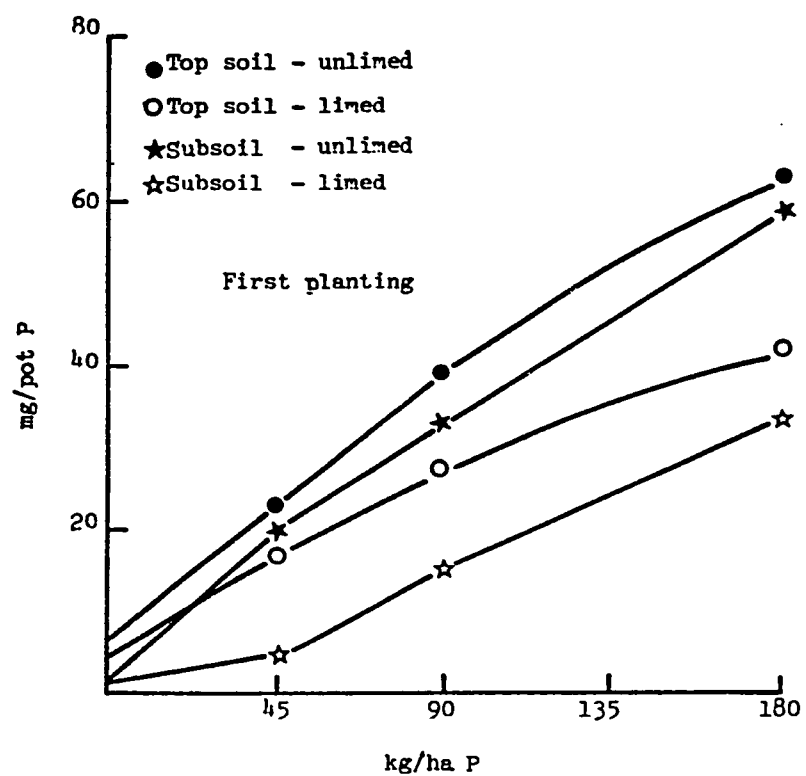
Appendix Figure 5. The effect of lime and phosphorus application on total P.



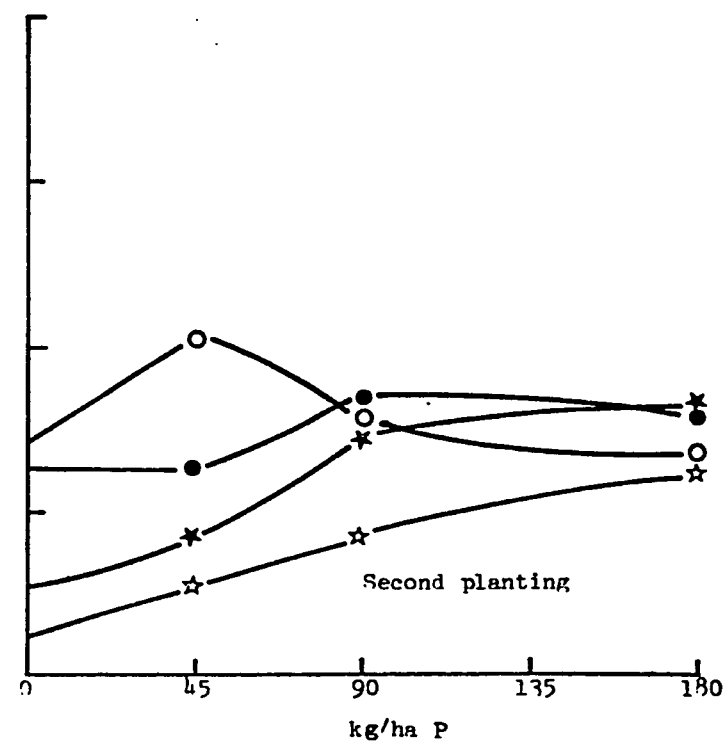
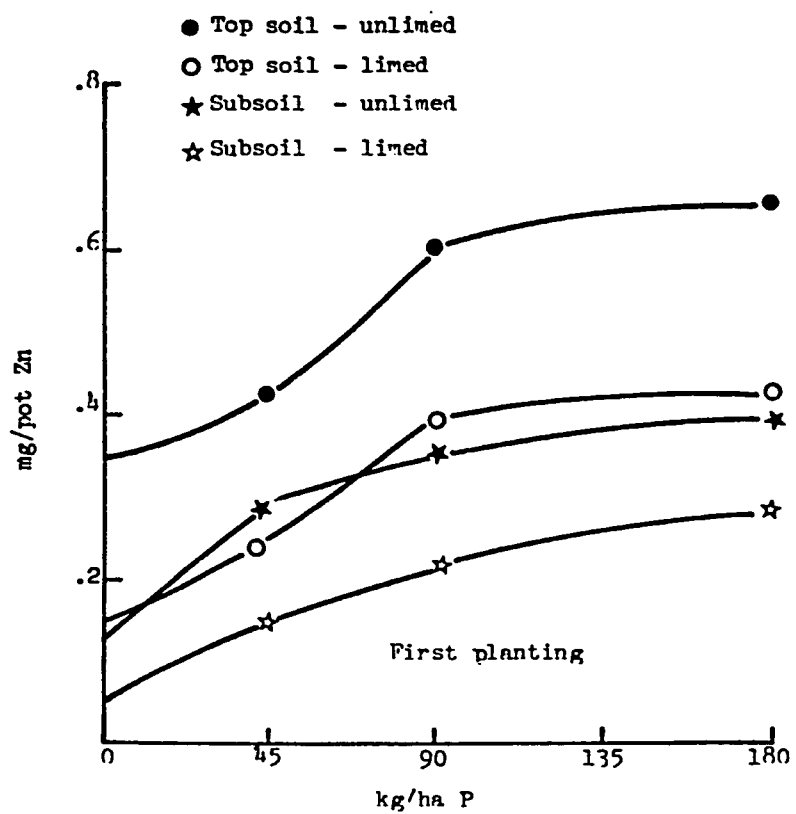
Appendix Figure 6. The effect of lime and phosphorus application on maize growth.



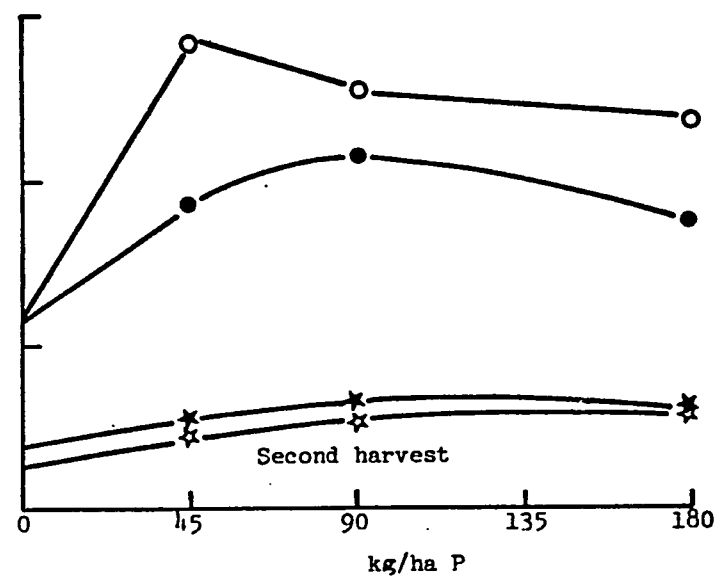
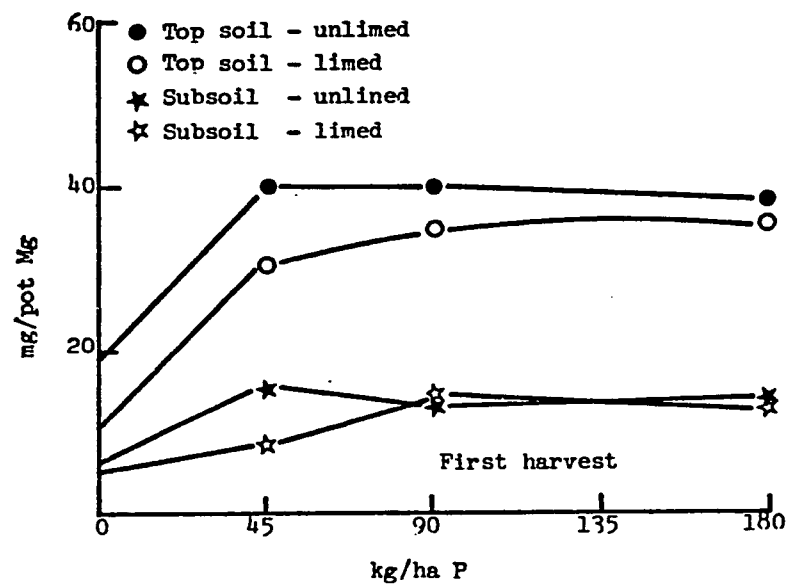
Appendix Figure 7. The effect of lime and phosphorus application on calcium uptake.



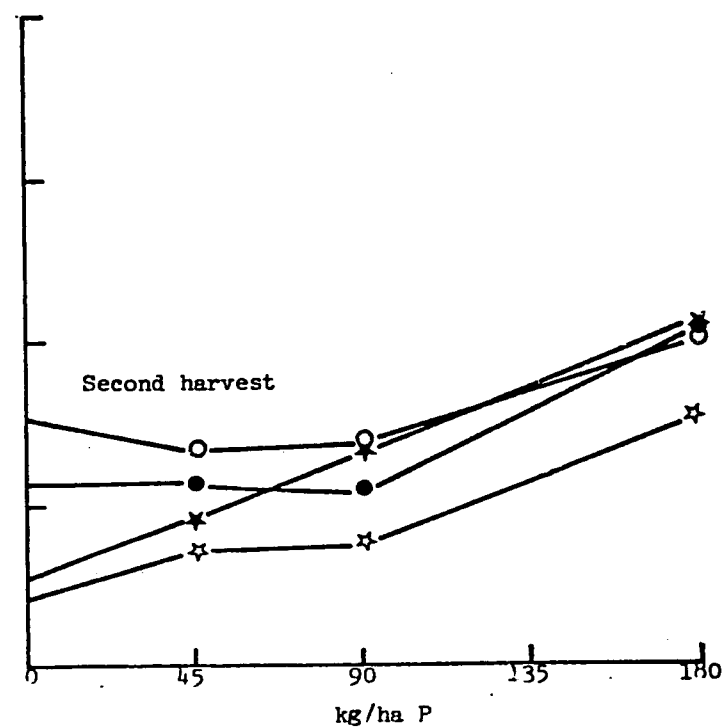
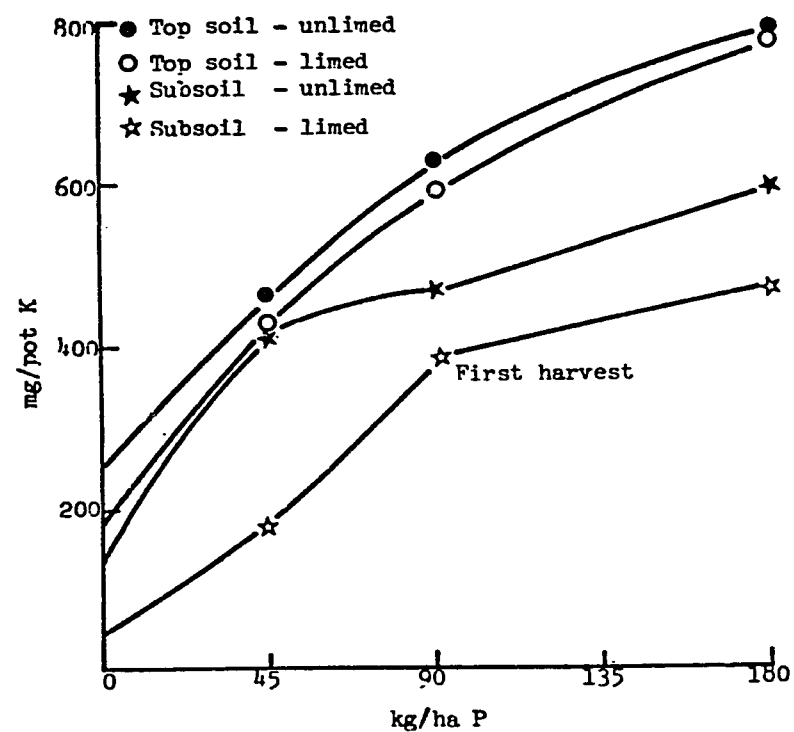
Appendix Figure 8. The effect of lime and phosphorus application on phosphorus uptake.



Appendix Figure 9. The effect of lime and phosphorus application on the uptake of zinc.



Appendix Figure 10. The effect of lime and phosphorus application on Magnesium uptake.



Appendix Figure 11. The effect of lime and phosphorus application on potassium uptake.

